

UNCLASSIFIED

AD 284 395

*Reproduced
by the*

**ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA**



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

62-4-6

284 395
CATALOGED BY ASTIA
AS AD No. _____
284395

ASD-TDR-62-413

PERFORMANCE EVALUATION OF
PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES

Reinhold J. Gross

Clinton V. Eckstrom

TECHNICAL DOCUMENTARY REPORT NO. ASD-TDR-62-413
June 1962

Flight Accessories Laboratory
Aeronautical Systems Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

Project No. 6065, Task No. 606503

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified requesters may obtain copies of this report from the Armed Services Technical Information Agency, (ASTIA), Arlington Hall Station, Arlington 12, Virginia.

Copies of this report should not be returned to the Aeronautical Systems Division unless return is required by security considerations, contractual obligations, or notice on a specific document.

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 65p. Incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

(over)

1.6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

1. Parachute descents
2. Parachute fabrics
I. AFSC Project 6065, Task 6065-03
II. R. J. Gross
C. V. Eckstrom
III. In ASTIA collection

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 55p. Incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

(over)

1.6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

1. Parachute descents
2. Parachute fabrics
I. AFSC Project 6065, Task 6065-03
II. R. J. Gross
C. V. Eckstrom
III. In ASTIA collection

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 65p. incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

(over)

1. 6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained in 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

1. Parachute descents
2. Parachute fabrics
I. AFSC Project 6065,
Task 6065-03
II. R. J. Gross
C. V. Eckstrom
III. In ASTIA collection

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 65p. incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

(over)

1. 6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

1. Parachute descents
2. Parachute fabrics
I. AFSC Project 6065,
Task 6065-03
II. R. J. Gross
C. V. Eckstrom
III. In ASTIA collection

FOREWORD

This Technical Documentary Report was prepared by the Retardation and Recovery Branch, Flight Accessories Laboratory, Directorate of Aeromechanics, Deputy Commander/Technology, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

The evaluation of the performance of solid-cloth parachute canopies with varying cloth permeabilities was initiated in August 1958 by the Parachute Branch, Aeronautical Accessories Laboratory, Wright Air Development Center, and continued until May 1960. Work was conducted under Project No. 6065, Task No. 606503 under the direction of project engineers George A. Solt, Jr. and Reinhold J. Gross. In May 1960, as a result of reorganization, this effort was transferred to the Retardation and Recovery Branch, Flight Accessories Laboratory, Aeronautical Systems Division, under the guidance of Mr. Reinhold J. Gross. Mr. Clinton V. Eckstrom served as associate task engineer during the last phases of the program, which were completed in January 1962.

The authors wish to acknowledge and express their appreciation to the personnel of the 6511th Test Group (Parachute), NALF, El Centro, California, who conducted the actual parachute tests and who acquired the required data.

ABSTRACT

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of 1.6-ounce nylon cloth. They had permeabilities ranging between 50 and 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions.

The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

PUBLICATION REVIEW

Publication of this technical documentary report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

TABLE OF CONTENTS

	Page
Introduction	1
General	1
Background	1
Purpose of Study	2
Test Equipment	2
Parachute Canopies	2
Supporting Equipment	3
Tests and Deployment Methods	3
Test Procedures and Analyses of Test Results	4
General	4
Whirl-Tower Tests	4
Drop Tests from Aircraft	10
Special Tests	17
Conclusions	19
List of References	20
Appendix - Illustrations	21

LIST OF ILLUSTRATIONS

Figure	Page
1 Rubber Torso Dummy with Tensiometers Installed in Canopy Risers	22
2 Sideview of B-4 Backpack Installed on Dummy	23
3 Backview of B-4 Backpack Installed on Dummy	24
4 Packing Procedure Incorporating Line Twists	25
5 Snatch Force of Parachute Canopy and Time to Snatch Versus Release Velocity (Whirl-Tower Tests)	26
6 Filling Time of Canopy Versus Cloth Permeability Group for Various Release Velocities (Whirl-Tower Tests)	27-28
7 Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 100 Knots (Whirl-Tower Tests)	29
8 Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 125 Knots (Whirl-Tower Tests)	30
9 Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 150 Knots (Whirl-Tower Tests)	31
10 Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 175 Knots (Whirl-Tower Tests)	32
11 Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 200 Knots (Whirl-Tower Tests)	33
12 Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 225 Knots (Whirl-Tower Tests)	34
13 Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 125 Knots (Whirl-Tower Tests)	35
14 Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 150 Knots (Whirl-Tower Tests)	35
15 Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 175 Knots (Whirl-Tower Tests)	36
16 Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 200 Knots (Whirl-Tower Tests)	37
17 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 1 (Whirl-Tower Tests)	38
18 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 2 (Whirl-Tower Tests)	39

LIST OF ILLUSTRATIONS (Continued)

Figure	Page
19 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 3 (Whirl-Tower Tests)	40
20 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 4 (Whirl-Tower Tests)	41
21 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 5 (Whirl-Tower Tests)	42
22 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 6 (Whirl-Tower Tests)	43
23 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 7 (Whirl-Tower Tests)	44
24 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 8 (Whirl-Tower Tests)	45
25 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 9 (Whirl-Tower Tests)	46
26 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 10 (Whirl-Tower Tests)	47
27 Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 11 (Whirl-Tower Tests)	48
28 Opening Time of Canopy Versus Cloth Permeability Group for Twisted-Line Tests: Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)	49
29 Down Time of Parachute Versus Cloth Permeability Group for Twisted-Line Tests: Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)	50
30 Ratio of Opening Time to Down Time Versus Cloth Permeability Group for Twisted-Line Tests: Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)	51
31 Ratio of Opening Time and Untwisted Time to Down Time Versus Cloth Permeability Group for Twisted-Line Tests: Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)	52
32 Twisted and Knotted Suspension Lines on a Parachute Canopy from Cloth Permeability Group 3 (Test No. 58-1053)	53

LIST OF ILLUSTRATIONS (Continued)

Figure	Page
33 Canopy from Cloth Permeability Group 4 That Failed to Inflate Before Ground Impact. Suspension Lines are Knotted about Midpoint (Test No. 59-401)	54
34 Canopy from Cloth Permeability Group 9 That Failed to Inflate	55
35 Canopy from Cloth Permeability Group 11 That Failed to Inflate	56
36 Opening Time of Canopy Versus Cloth Permeability Group for Twisted-Line Tests: Release Velocity, 150 Knots; Altitude, 500 Feet (Drops from Aircraft)	57
37 Opening Time of Canopy Versus Cloth Permeability Group for Twisted-Line Tests: Release Velocity, 225 Knots; Altitude, 500 Feet (Drops from Aircraft)	58
38 Canopy from Cloth Permeability Group 8 That Failed to Inflate: Release Velocity, 225 Knots	59
39 Canopy from Cloth Permeability Group 11 That Failed to Inflate: Release Velocity, 225 Knots	60
40 Comparison of Canopy Snatch and Opening Forces Experienced During Drop Tests from Whirl Tower and Aircraft: Release Velocity, 150 Knots	61
41 Average Cloth Permeability Values for All Available Canopies	62
42 Average Cloth Permeability Values for All Permeability Groups in 1947 and in 1959 (Before Initiation of Drop Testing)	63
43 Average Cloth Permeability Values for All Permeability Groups in 1947 and in 1959 (After Completion of Drop Testing)	64
44 Change of Average Cloth Permeability with Number of Canopy Deployments for Three Permeability Groups	65

INTRODUCTION

GENERAL

The performance characteristics of solid-cloth parachute canopies in terms of filling time, opening force, rate of descent, and stability depend upon the air permeability of the cloth of which the parachute canopies are constructed. Although the relationship of some of the performance characteristics to cloth permeability had previously been experimentally determined (Ref. 1), this physical phenomenon has only recently been explained with the development of the concept of "effective porosity" (Ref. 2). In addition, the effect of cloth permeability or porosity upon the drag and stability coefficients of various parachute canopies was established by means of model tests (Ref. 3). Virtually no experimental data were available, however, by which the effects of aging upon cloth permeability and, consequently, upon the opening characteristics of solid-cloth parachute canopies could be determined.

BACKGROUND

In the late stages of World War II, a parachute failed to open during dummy tests. This failure was probably due to the high permeability of the canopy cloth. At the time, very little data were available concerning the performance characteristics of high-permeability parachute canopies. Therefore, a test program was started to investigate the effects of cloth permeability on the performance of parachutes. One hundred and twenty flat-circular parachute canopies each with a 24-foot diameter were constructed of cloth, which varied in permeability from 50 to 270 cubic feet of air per square foot of cloth per minute ($\text{ft}^3/\text{ft}^2/\text{min}$) at 1/2-inch water-pressure differential (wpd). These parachutes were manufactured by the Pioneer Parachute Company in 1947 and their cloth permeabilities were determined by the Cheney Brothers Laboratory.

All parachute canopies were constructed of 1.6-ounce nylon cloth, which was manufactured by Cheney Brothers according to Specification AN-C-127 (superseded by MIL-C-7020, Type II). This cloth had a normal permeability of 100 to 160 $\text{ft}^3/\text{ft}^2/\text{min}$ at 1/2-inch wpd. The contractor modified the finishing techniques slightly by using the same basic fabric and subjecting it to greater or lesser calendering pressures to achieve lower or higher permeability than had been found in the run of regular production. Then all requirements for permeabilities lower than 170 $\text{ft}^3/\text{ft}^2/\text{min}$ were completed. To achieve permeabilities higher than 170 $\text{ft}^3/\text{ft}^2/\text{min}$, the contractor wove a special fabric. This weaving was accomplished with a minimum change in construction by using the same type, size, and number of threads in both warp and filling, but by putting five turn twists per inch in the filling yarn instead of the one turn twist normally used. This technique permitted the attainment of a maximum cloth permeability of over 250 $\text{ft}^3/\text{ft}^2/\text{min}$, and varying the calendering pressure permitted the permeability range between 160 and 275 $\text{ft}^3/\text{ft}^2/\text{min}$ to be filled in.

During 1947, the Pioneer Parachute Company conducted 1164 whirl-tower drop tests on the parachutes at release velocities ranging from 50 to 225 miles per hour. Details of these tests and the results obtained can be found in References 1 and 4.

On 21 April 1958, more than 10 years after the original tests were conducted, a supplementary test program was initiated. At this time, 51 canopies of the original 120 that were manufactured by the Pioneer Parachute Company were available and in a satisfactory condition for further testing. The actual testing of the parachute canopies commenced during the spring of 1959 and continued through the fall of 1960.

Although no record was available, we assumed that none of the parachute canopies were used in testing during the period between 1947 and 1959. During this period, the canopies had been stored indoors and were not exposed to any abnormal atmospheric conditions other than those found in non-airconditioned or temperature-controlled buildings.

PURPOSE OF STUDY

The purpose of this supplementary test program was to validate the original test results under actual operational conditions and to determine the effects of age on the permeability of canopy cloth and on the opening characteristics of the canopy. In addition to the determination of canopy opening characteristics, twisted suspension-line tests were conducted to determine if the parachutes would satisfy requirements for personnel-parachute applications.

TEST EQUIPMENT

PARACHUTE CANOPIES

The parachute canopies were of standard flat-circular design; each canopy was 24 feet in diameter with suspension lines of 16 feet 10 inches in length. The canopies were manufactured according to Air Force Drawing No. 42G2000. The cloth used had been manufactured according to Specification AN-C-127 and deviations as described in the Introduction.

All parachute canopies were originally rated as to their permeability and grouped into 11 groups (Ref. 1). With 120 canopies available in 1947, there were several canopies in each permeability group. With only 51 canopies remaining for testing in 1958, some permeability groups had only a few canopies. The number of canopies available in each group are shown in Table 1.

TABLE 1
CLOTH PERMEABILITY GROUPS

Group Number	Permeability $Fr^2 / Fr^2 / \text{Min}$	Number of Canopies
1	50- 70	2
2	71- 90	2
3	91-110	10
4	111-130	8
5	131-150	4
6	151-170	7
7	171-190	6
8	191-210	4
9	211-230	3
10	231-250	2
11	251-270	3
Total		51

SUPPORTING EQUIPMENT

Rubber-torso dummies weighing approximately 225 pounds, which included dummy-borne instrumentation, were used as the suspended drop-test weights (Figure 1).

The parachute canopies were packed in a B-4 backpack, Air Force Drawing No. 50J6876 and were attached to the rubber-torso dummy (Figures 2 and 3) with a B-1 harness, Air Force Drawing No. 50J6858. An A-3 pilot chute, Air Force Drawing No. 50J6811, was attached to the apex of the 24-foot canopy with a 32-inch bridle line. Air permeability readings of the canopy cloth were made according to Federal Textile Testing Specification CCC-T-191b, Method 5450, on Frasier Machines 80a and 207.

Cameras providing still photographs and ground-to-air 16-mm motion pictures, which were taken at speeds of 64 frames per second, were used to record the tests. All time recordings of the drop tests were obtained by hand-operated stop watches. These time recordings were checked by the evaluation of available film records.

TESTS AND DEPLOYMENT METHODS

The 6511th Group (Parachute), El Centro, California, accomplished all of the testing under Test Program No. FTL-147. Drop tests were made from both aircraft and a whirl tower. The aerial tests were made from C-119 and C-130 aircraft. A hinged metal platform was used to launch the dummy. This platform allowed the dummy to slide out of the aircraft and reduced the tumbling tendency of the dummy. Opening of the parachute pack was initiated by a 15-foot static line that was attached to the floor of the aircraft. The pilot chute, which was permanently attached to the canopy, deployed the parachute canopy first. Twisted suspension lines were used in all of the drops from aircraft; no dummy-borne instrumentation was used. The suspension lines were twisted between the skirt of the canopy and a point 30 inches below the skirt of the canopy. The canopy was rotated 360 degrees in a counterclockwise direction for three turns. To untwist, the canopy would have to rotate in a clockwise direction (Figure 4).

The whirl-tower drop tests were made from a gondola that was attached to a rotating vertical shaft by a steel cable and a horizontal boom. The gondola moved in a circular path that was 334 feet in diameter and 120 feet above the ground. The dummy was electrically released from the gondola, and a 13-inch static line attached to the gondola activated the parachute ripcord. The canopy was also deployed first. Two tensiometers with a 10-second time base and a 7500-pound force range were installed on modified harness risers and utilized during the initial tests. During subsequent tests, strain-gage tensiometers were installed in the harness risers and were used with dual-channel telemetry to record snatch and opening forces on all whirl-tower drops.

The whirl tower of the Pioneer Parachute Company used for the 1947 tests swung the parachute in a horizontal circle 200 feet in diameter at a height of 65 feet above the ground. Prior to deployment of parachute, boom was allowed to rotate freely with the parachute remaining attached to the whirl-tower boom; therefore, the tests would not quite simulate finite mass conditions.

TEST PROCEDURES AND ANALYSES OF TEST RESULTS

GENERAL

Air permeability readings of the canopy cloth were taken in a marked area of each section of each canopy before the particular canopy was packed for the drop test. Permeability readings were taken again in the same areas after the canopy had been subjected to drop test.

Each canopy was subjected to the following drop tests in the order listed:

1. Two twisted-line tests in which the parachutes were released from aircraft that were flying at speeds of 110 knots IAS and at altitudes of 500 feet;
2. Six performance tests in which the parachutes were released from the whirl tower at speeds of 100, 125, 150, 175, 200, and 225 knots, successive, .
3. One twisted-line test in which parachute was released from an aircraft that was flying at a speed of 175 knots IAS and at an altitude of 500 feet;
4. One twisted-line test in which parachute was released from an aircraft that was flying at a speed of 225 knots IAS and at an altitude of 500 feet.

If a canopy was severely damaged during any one of the drop tests, no further tests were made on that canopy.

WHIRL-TOWER TESTS

Instrumented whirl-tower tests were conducted on 176 canopies; 164 provided some useful data. The tests were conducted at release velocities of 100, 125, 150, 175, 200, and 225 knots. These tests, together with the results obtained, are listed in Table 2.

TABLE 2

RESULTS OF WHIRL-TOWER DROP TESTS

Canopy No.	Serial No. of Canopy	Porosity Group	Drop Speed (kts.)	Snatch Time (sec.)	Snatch Force (lbs.)	Opening Time (sec.)	Opening Force (lbs.)	Remarks
1	322556	1	100		950	2.0	800	Pilot chute destroyed
			125		1275	1.2	1530	
			150	0.37	1500	1.12	2980	
			175	0.45	1390	1.10	3430	
			200	0.36	3100	0.97	4970	
			225	0.32	3170	1.04	3800	
4	322598	2	125	0.71	1320	1.50	2080	
			150	0.60	1810	1.50	2330	
			175	0.54	2620	1.20	3780	

TABLE 2 (Continued)

Canopy No.	Serial No. of Canopy	Porosity Group	Drop Speed (kts.)	Snatch Time (sec.)	Snatch Force (lb.)	Opening Time (sec.)	Opening Force (lbs.)	Remarks
6	322506	3	125	0.65	1040	1.55	1675	Opening right before landing
			200	0.35	1530	1.20	2940	
			225	0.33	2200	0.85	4600	
13	322507	3	125		950	1.50	1100	
			150	0.60	1460	1.50	2220	Pilot chute destroyed Minor damage Pilot chute destroyed
			175	0.47	1840	1.15	3580	
			200	0.39	2025	1.03	3975	
			225		1700	0.90	4330	
12	322508	3	100		1350	2.00	1450	Pilot chute destroyed
			125		1750	1.30	1650	
			150	0.50	1490	1.20	2280	
			175	0.57	1550	1.27	3300	
			200	0.36	2150	0.97	3500	Gore 5 destroyed
			225	0.37	2050	1.05	3760	
14	322512	3	150	0.57	1430	1.21	2620	
9	322586	3	100	0.78	980	1.73	1530	
5	322504	3	100		600	1.60	950	Minor damage
17	322510	4	100		1200	2.10	1500	
			175	0.40	1550	1.15	2770	
			200	0.38	2240	1.32	2400	
			225	0.41	3880			Major damage
16	322514	4	125	0.76	930	1.50	1800	
			150	0.48	960	1.38	2225	
			175		1396	1.20	3945	
15	322519	4	100	0.69	980	2.00	1300	Canopy inversion - major damage
			125	0.59	1080	1.65	1700	
			150	0.58	1430	1.29	2770	
			175	0.43	2010	1.10	3840	
			200	0.36	1875	0.74	4650	
18	322546	4	100		950	2.00	1050	
20	322540	4	100		800	1.90	1000	
			125	0.55	1170	1.55	1830	
			150	0.61	1300	2.10	1000	
			175	0.47	1480	1.10	2820	
			200		2510	0.90	3140	
21	322543	4	100	0.64	825	1.94	1300	
			125	0.59	1035	1.60	1490	
			150	0.60	1780	1.47	1720	
			175	0.40	1070	1.10	3300	
			200	0.37	1580	1.56	1640	
			225	0.36	2350	1.17	3340	

TABLE 2 (Continued)

Canopy No.	Serial No. of Canopy	Porosity Group	Drop Speed (kts.)	Snatch Time (sec.)	Snatch Force (lbs.)	Opening Time (sec.)	Opening Force (lbs.)	Remarks
18	322546	4	100 125	 0.65	950 980	 1.20	1050 2350	Canopy inversion - major damage
19	322549	4	100 125 150 175 200 225	0.77 0.71 0.46 0.45 0.36 0.31	790 1010 2265 1640 2720 2770	2.05 1.66 1.03 1.28 1.23 1.07	1540 1800 3720 2215 2130 4675	Minor damage
23	322830	5	100 125 150 175 225	0.79 0.62 0.44 0.44 0.62	750 1255 840 4300 1425	2.03 1.42 1.39 1.09 1.72	1445 1630 1750 7350 1225	
24	322525	5	125 150 175 200 225	0.55 0.55 0.44 0.44 0.30	1680 1280 1610 1940 3320	1.35 1.25 1.09 1.08 0.80	2610 3105 3070 3845 3205	Minor damage
25	322829	5	100 125	 0.56	 1340	2.00 1.00	1225 2630	Canopy inversion - major damage
26	322528	5	100 125 150 175 200 225	 0.55 0.32 0.43 0.41 0.37	1150 970 1250 2090 6410 2665	1.70 1.36 1.08 1.10 0.96 0.93	1450 1760 2350 3220 6410 4710	"flower" deployment "flower" deployment
28	322527	6	100 125 150 175 200 225	 0.63 0.55 0.47 0.50 0.29	750 900 1630 1550 1500 1450	 1.44 1.16 1.36 1.00	 2570 2530 1870 4545	Pilot chute destroyed
32	322591	6	125 150 175 200 225	0.75 0.46 0.45 0.37 0.33	1240 1340 2350 2060 3150	1.65 1.30 1.42 1.33 1.50	1420 1460 1675 1680 2840	Pilot chute destroyed
34	322536	7	100 125 150 175	 0.69 0.65 0.47	900 760 1520 1760	2.10 1.75 1.38 1.15	1200 1570 2320 2910	

TABLE 2 (Continued)

Canopy No.	Serial No. of Canopy	Porosity Group	Drop Speed (kts.)	Snatch Time (sec.)	Snatch Force (lbs.)	Opening Time (sec.)	Opening Force (lbs.)	Remarks
35	322537	7	200	0.37	2230	1.01	3300	Pilot chute destroyed
			225	0.30	3310	0.95	6100	
			100		1100	2.10	1125	
			125	0.62	1315	1.50	1445	
			150	0.53	1500	1.35	1580	
			175	0.52	2075	1.17	3200	
			200	0.63	1795	1.32	5500	
36	322596	7	225	0.34	4600	0.97	7370	Pilot chute destroyed
			100	0.57	1420			
			125	0.60	1190	1.40	2320	
			150	0.60	1340	1.38	2020	
			175	0.45	1240	1.10	3080	
			200	0.36	2285	1.10	3275	
			225	0.30	3650	0.98	7150	
39	322563	7	125	0.60	955	1.85	1030	Pilot chute destroyed
			150	0.55	965	1.30	1145	
			175	0.50	1830	0.90	2610	
40	322532	8	100	0.74	740	2.12	1240	Inversion - major damage "flower" deployment
			125	0.83	1375	1.96	1300	
			150	0.57	1420	1.72	1540	
			175	0.44	5100	1.06	7490	
			200	0.45	1575	1.87	950	
			225	0.61	1600	1.46	1890	
			100	0.80	850	1.99	1200	
41	322560	8	125	0.60	1225	1.58	1225	
			150	0.49	1960	1.68	1260	
			175	0.53	2280	1.31	2150	
			225	0.35	3030	1.00	4250	
			100	0.62	1375	1.80	1075	
			125	0.69	1250	1.91	1420	
			150	0.52	1540	1.35	1480	
42	322561	8	175	0.50	1490	1.54	1560	Pilot chute destroyed
			200	0.40	1950	1.51	1475	
			225	0.33	1700	1.54	1375	
			125	0.64	1295	1.80	1050	
			150	0.66	1380	1.71	1410	
			175	0.47	1960	2.17	2020	
			200	0.38	1650	1.44	1560	
43	322562	8	225	0.42	2265	1.23	2410	Pilot chute destroyed

TABLE 2 (Continued)

Canopy No.	Serial No. of Canopy	Porosity Group	Drop Speed (kts.)	Snatch Time (sec.)	Snatch Force (lbs.)	Opening Time (sec.)	Opening Force (lbs.)	Remarks
44	322565	9	125	0.76	880	2.43	820	Pilot chute destroyed Pilot chute destroyed Inversion - major damage "flower" deployment Minor damage Pilot chute destroyed
			150	0.60	1750	1.55	1620	
			175	0.50	1620	1.46	1645	
			200	0.39	2075	1.47	1515	
			225	0.33	2285	1.12	2425	
45	322577	9	100	0.85	780	2.20	860	
			125	0.76	1000	2.80	920	
			150	0.50	1610	1.80	1340	
			175	0.70	1880	1.50	1240	
			200	0.33	1755	1.47	1325	
46	322575	9	225	0.32	2260	1.44	1800	
			100	0.90	660	2.55	680	
			175	0.30	1830	2.07	800	
47	322573	10	100	0.77	900	2.07	800	Failed to open
			125	0.76	1330	1.98	900	
			150	0.57	1570	1.66	1140	
			175	0.43	4700	1.56	2900	
			225	0.38	3425	1.50	1850	
48	322679	10	125	0.64	1120	2.16	950	
			150	0.60	1775	1.75	1200	
			175	0.44	1745	1.83	1050	
			200	0.33	4740	1.67	3500	
			225	0.38	2270	1.37	2190	
50	322677	11	100	0.96	780		660	Minor damage
			125	0.65	1140	2.79	760	
			175	0.60	1710	1.60	1260	
			200	0.46	2700	1.55	1320	
			225	0.33	3250	1.58	1200	
49	322684	11	125	0.76	1110	1.61	1950	Pilot chute destroyed
			150	0.53	1250	1.66	1240	
			175	0.46	1725	2.00	960	
			200	0.32	2525	1.39	1910	
			225	0.35	1370	1.40	2475	

Analyses of the performances of the canopies under the whirl-tower tests follow.

Snatch Force and Time

The snatch force and time to snatch did not change when cloth permeability changed. The magnitude of the snatch force is, therefore, a function of the mass of the parachute.

differential velocity of the body and parachute, and the elongation properties of the suspension-line material. The snatch force did increase from approximately 1000 pounds at a test velocity of 100 knots to approximately 2000 pounds at a test velocity of 200 knots. As the snatch force increased with velocity, the time to snatch decreased from 0.75 second (approximately) to 0.375 second (approximately). These relationships are shown in Figure 5.

Filling Time

The filling time of the canopy as a function of permeability group is shown in Figure 6 for each test velocity. Figure 6 shows a slight increase in filling time with increasing cloth permeability for all test velocities. It also shows that the filling time decreases with increasing velocity if the filling time for any particular permeability group is considered as a function of test velocity.

Opening Force and Time

The opening force of the parachute canopy increased as the release velocity increased, as shown in Figures 7 through 12. The opening force decreased with increasing cloth permeability for any given test velocity. An example would be the opening force at a release velocity of 175 knots. In Permeability Group 3 the average force was 3500 pounds, while in the higher Permeability Group 9 the average opening force was measured to be only about 1500 pounds.

The rubber-torso dummy (suspended weight) in a number of instances tended to rotate approaching an axis perpendicular to the direction of parachute deployment and resulted in forces of varied magnitude. However, the forces pertinent to each specific test and permeability group indicated clearly the influence of permeability on the opening force.

The opening times are also shown in Figures 7 through 12. The opening time here is defined as the time from launch to a point where the canopy is initially fully inflated, or essentially the sum of the time until snatch force occurs and the filling time. Opening forces and opening times measured during the initial tests in 1947 and reported in Reference 1 are also shown. Comparing these data indicate that both sets of test results are of the same order of magnitude.

It is also of interest to know how the ratio of opening force to snatch force varies with release velocity for different permeabilities of canopy cloth. Figures 13 through 16 give the ratio of opening to snatch force. These figures show that at lower release velocities the opening force was greater than the snatch force for all except the higher permeabilities (Groups 9, 10, and 11). At higher release velocities, the snatch force was greater and the point where the snatch force became equal to the opening force occurs in the intermediate permeability groups.

Figures 17 through 27 show representative force times that were obtained during the deployment and opening sequences of parachute canopies of each one of the 11 permeability groups.

Opening Reliability and Strength of Canopy

Of the 176 whirl-tower drop tests conducted, only 2 canopies failed to open. Both of these failures occurred at a release velocity of 100 knots. One of the canopies that failed was from Permeability Group 4, and its failure to open was attributed to tangled and

knotted suspension lines. The other canopy was from Permeability Group 11 and its failure to open may have been because of its high cloth permeability. This canopy had reached 3/4 inflation at point of ground impact. On other tests conducted with this canopy at release speeds varying from 125 to 225 knots, no apparent opening hesitations were noted.

Although only two canopies failed to open, there were several drops in which canopies were damaged severely enough to prevent further testing of that particular canopy.

At a release velocity of 125 knots, two canopies were badly damaged. One was from Group 3 and one was from Group 4. In both instances, the canopies inverted during inflation resulting in cloth burns, damaged panels, and broken suspension lines.

At a release velocity of 150 knots, a canopy from Permeability Group 3 suffered a blown gore.

At a release velocity of 175 knots, four canopies were damaged. They were one each from Groups 3 and 7 and two from Group 9.

At a release velocity of 200 knots, four canopies were extensively damaged. They were two each from Permeability Groups 3 and 4. In addition, there were six tests in which the pilot chutes were destroyed.

One instance of major damage to the canopy occurred at the release velocity of 200 knots. The canopy had a measured force of 4,650 pounds. There were, however, eight other cases where the measured opening force exceeded 4,650 pounds and the parachutes survived undamaged. These forces far exceeded the highest average forces measured during the initial test program and documented in Reference 1.

At a release velocity of 225 knots, there were 11 instances where the pilot chutes were destroyed. A canopy from Permeability Group 4 had four suspension lines broken and a canopy from Group 5 had three panels damaged. It should be noted that each canopy was tested at a release velocity of 100 knots first and then at successively higher velocities so a panel might have been damaged at a low velocity, thereby reducing the number of canopies subjected to tests at the higher velocities.

DROP TESTS FROM AIRCRAFT

Twisted-Line Tests at Release Velocities of 110 Knots

Twisted-line drop tests were conducted on 101 canopies in which parachutes were released from aircraft that were flying at 110 knots and at an altitude of 500 feet. These tests and the test results obtained are listed in Table 3.

TABLE 3

RESULTS OF TWISTED-LINE TESTS WHERE PARACHUTES WERE
RELEASED FROM AIRCRAFT AT VELOCITIES OF 110 KNOTS

Canopy No.	Serial No. of Canopy	Porosity Group	Test No.	Opening Time (sec.)	Untwist Time (sec.)	Down Time (sec.)	Remarks
2	552	I	58-974	2.8	7.7	20.8	failed to open
2	552	I	58-1238	2.0	4.8	17.6	
1	556	I	59-352	3.5	0	13.1	
1	556	I	59-490	3.2	4.6	15.7	
4	598	II	58-969	3.8	4.2	15.8	
4	598	II	58-1236	4.0	7.0	12.3	
10	502	III	59-355	3.8	3.2	15.9	
10	502	III	59-484	3.6	9.2	14.6	
5	504	III	59-353	3.7	3.8	17.3	
5	504	III	59-485	3.0	4.7	17.0	
6	506	III	58-975	3.1	5.0	18.1	
6	506	III	58-1237	3.4	4.8	14.9	
13	507	III	58-971	3.3	7.0	16.9	
13	507	III	58-1239	3.0	3.4	13.6	
12	508	III	58-1054	3.0	5.9	14.1	
12	508	III	59-138	3.4	6.6	15.0	
14	512	III	58-1053			6.6	
14	512	III	59-139	3.6	4.3	16.0	
9	586	III	59-648	3.4	4.2	15.2	
9	586	III	59-701	3.4	5.2	14.9	
8	588	III	59-647	3.4	3.6	16.9	
8	588	III	59-710	3.4	4.5	11.6	
7	589	III	58-1555	3.1	4.6	17.5	
7	589	III	59-277	2.9	6.2	18.4	
17	510	IV	58-970	3.0	0	18.8	
17	510	IV		4.0		10.5	
16	514	IV	59-636	2.4	2.1	16.0	
16	514	IV	59-709	2.6	4.4	16.5	
15	519	IV	59-631	2.9	3.5	16.4	
20	540	IV	59-395	3.0	4.8		
20	540	IV	59-633	3.0	3.3	17.2	
21	543	IV	59-401				
21	543	IV	59-511	3.9	2.2	13.3	
22	545	IV	59-643	3.0	7.3	19.2	
22	545	IV	59-706	4.0	4.8	11.7	
18	546	IV	59-390	3.1			
18	546	IV	59-507	3.0	11.2	14.8	
19	549	IV	58-961	5.6	3.5	18.0	
19	549	IV	58-1551	4.0	4.5	13.6	
24	525	V	58-1556	3.9	10.0	14.2	
24	525	V	59-199	3.5	4.0	15.9	
26	528	V	59-273	3.0	5.5	16.9	
26	528	V	59-397	3.7	4.7		
25	829	V	59-399	4.1	4.4		

TABLE 3 (Continued)

Canopy No.	Serial No. of Canopy	Porosity Group	Test No.	Opening Time (sec.)	Untwist Time (sec.)	Down Time (sec.)	Remarks
23	830	V	59-645	3.4	7.0	17.5	
23	830	V	59-708	3.0	5.0	15.8	
30	520	VI	59-392	4.0	6.3		
30	520	VI	59-508	4.6	5.5	13.2	
29	523	VI	59-350	3.3	6.5	14.5	
29	523	VI	59-486	3.2	5.3	13.9	
31	526	VI	59-351	3.8	5.3	14.1	
31	526	VI	59-491	3.6	3.6	15.2	
28	527	VI	59-351	3.9	0	13.8	
28	527	VI	59-488	3.7	2.6	16.2	
27	529	VI	59-276	2.7	6.0	16.3	
27	529	VI	59-489	3.6	2.0	15.3	
32	591	VI	58-1058	3.0	2.2	16.1	
32	591	VI	59-131	4.3	3.8	13.5	
33	594	VI	59-393	3.6	4.2		
33	594	VI	59-509	3.6	3.6	15.4	
37	530	VII	59-634	3.0	5.2	15.3	
37	530	VII	59-703	4.1	3.6	12.2	
38	531	VII	59-635	3.6	1.8	13.8	
38	531	VII	59-702	2.7	4.4	13.1	
34	536	VII	58-972	3.5	0	19.1	
34	536	VII	58-1240	3.4	7.3	12.7	
35	537	VII	59-197	5.7	4.2	11.2	
39	563	VII	59-274	4.0	8.0	14.1	
39	563	VII	59-396	5.3			
36	596	VII	59-354	4.8	3.0	11.6	
36	596	VII	59-483	3.2	7.8	13.6	
40	532	VIII	59-707	4.0	4.5	14.0	
40	532	VIII	59-723	3.1		19.0	
41	560	VIII	59-630	4.0	2.6	14.3	
41	560	VIII	59-704	4.9	15.0	22.0	
42	561	VIII	59-278	5.9	4.3	11.8	
42	561	VIII	59-402	5.0	4.6		
43	562	VIII	59-389	7.3	0	7.5	
43	562	VIII	59-505	4.0	5.8	14.5	
44	565	IX	58-1055	4.0	9.4	13.8	
44	565	IX	59-195	4.0	1.9	16.1	
46	575	IX	58-1052	3.6	3.4	12.7	
46	575	IX	59-198	6.7	2.8	10.6	
45	577	IX	59-487	4.2	7.2	13.6	
45	577	IX	59-632			7.0	failed to open
47	573	X	59-275	5.0	4.8	13.4	
48	679	X	59-400	5.5			never untwisted
48	679	X	59-586			7.4	failed to open

TABLE 3 (Continued)

Canopy No.	Serial No. of Canopy	Porosity Group	Test No.	Opening Time (sec.)	Untwist Time (sec.)	Down Time (sec.)	Remarks
50	677	XI	58-1558	4.3	7.8	13.0	never untwisted failed to open (line over canopy) failed to open
50	677	XI	59-196	7.2		9.4	
51	680	XI	59-649			7.9	
51	680	XI	59-205				
49	684	XI	59-394	3.0			
49	684	XI	59-510	4.6	3.3	11.7	

Analyses of the performances of the canopies under these tests follow.

1. Opening Time of Canopy

The opening time of the parachute canopies tested varied between 2 to 4 seconds for Permeability Group I and increased to a range of between 4 to 7 seconds for Permeability Group II, as shown in Figure 28. All tests were conducted with twisted lines (see Figure 4). In some drop tests, the canopy would rotate during the period of line and canopy stretch, which resulted in partial or total untwisting of the suspension lines. In these instances, the inflation would be normal resulting in minimum opening times.

For the purpose of this evaluation, the opening time of the canopy is defined as that interval between release of the load from the test aircraft (parachute static line deployed) to the point where the canopy is first fully inflated prior to untwisting of the suspension lines.

The maximum opening time in each permeability group can be attributed in part to the twisted lines, which effectively shortens the line length to the point of twist. In some instances, the canopy would begin to inflate in a normal fashion but the effectively short length of the suspension line would turn the skirt of the canopy into the flow to the extent that it partially closed again before final inflation.

Figure 28 indicates that there is a linear increase in opening time with increasing cloth permeability within the spread of the test results obtained.

The average opening times of the canopies and the standard deviations of the test results are listed in Table 4. This table shows that the average opening time is increasing linearly with increasing cloth permeability from 2.87 seconds for Permeability Group I (50-70) to 4.77 seconds for the highest Group II (250-270). The standard deviation of the test results is also increasing as the cloth permeability increases.

TABLE 4

AVERAGE OPENING AND DOWN TIMES OF CANOPIES AND STANDARD DEVIATIONS
(TWISTED-LINE TESTS WHERE PARACHUTES WERE RELEASED FROM
AIRCRAFT AT VELOCITIES OF 100 KNOTS)

Porosity Group	No. of Tests	Opening Time (seconds)		Down Time (seconds)		Opening Time Down Time		Open and Untwist Down Time	
		M	SD	M	SD	M	SD	M	SD
1 (50-70)	4	2.87	± .58	16.8	± 2.30	0.180	± .070	0.414	± .097
2 (71-90)	2								
3 (91-110)	17	3.32	± .26	15.25	± 2.68	0.214	± .032	0.541	± .115
4 (111-130)	13	3.25	± .50	15.83	± 2.60	0.216	± .068	0.504	± .184
5 (131-150)	7	3.51	± .39	16.06	± 1.27	0.215	± .032	0.615	± .188
6 (151-170)	14	3.64	± .26	14.96	± .94	0.244	± .048	0.506	± .167
7 (171-190)	12	3.93	± .90	13.67	± 2.15	0.298	± .099	0.638	± .217
8 (191-210)	8	4.10	± .89	14.73	± 4.19	0.288	± .139	0.746	± .182
9 (211-230)	5	4.50	± 1.25	12.30	± 2.87	0.352	± .141	0.724	± .229
10 (231-250)	2								
11 (251-270)	4	4.77	± 1.52	10.50	± 1.98				
<p>Arithmetic Mean = $M = \frac{\sum X}{n}$</p> <p>Standard Deviation = $SD = \sqrt{\frac{\sum (M - X)^2}{n}}$</p>									

2. Down Time of Canopy

A consequence of the trend of increasing opening time with increasing cloth permeability is that the canopies in the higher permeability groups spend a longer period of time in a low drag configuration. This means that the higher permeability canopies cover a greater portion of the drop distance before opening, which results in shorter down times as shown in Figure 29.

Table 4 also lists the average down time and the standard deviation for the test results. These data show that the average down time is decreasing from 16.8 ± 2.30 seconds for Group 1 (50-70) to 10.50 ± 1.98 seconds for Group 11 (250-270).

The ratio of opening time to down time for these tests as a function of permeability group is presented in Figure 30. Failures to open are indicated by points falling above the line giving the ratio of opening time to down time equal to 1. Figure 30 shows that the canopies in the lower permeability groups required only a small portion of the total down time to open whereas a few of the canopies in the higher permeability groups required a larger portion of the down time to complete the opening process. The average value of the ratio of opening to down time as listed in Table 4 is increasing linearly with respect to cloth permeability, but one should note that the standard deviation of test results is quite large for the higher permeability ranges.

If the time to untwist is also considered, as in the ratio of opening plus untwist time to the down time as shown in Figure 31, we can see that two additional instances exist where the canopy failed to untwist before ground impact. Although Table 4 lists the average value of the ratio of opening plus untwist time to down time as increasing linearly from 0.414 ± 0.097 for Group 1 to 0.724 ± 0.229 for Group 11, a large standard deviation indicating the spread of test points is apparent. This deviation is also shown in Figure 31.

3. Opening Reliability

Of 101 twisted-line tests conducted at release velocity of 110 knots, there were six drops in which the canopies failed to inflate. One failure each occurred in Groups 3, 4, 9, and 10, and two failures occurred on successive drops of the same canopy in Group 11.

Canopies in Permeability Groups 3 and 4 had lines knotted as shown in Figures 32 and 33 as a result of the line twists and, therefore, were prevented from untwisting further than the location of the knots.

The canopy in Permeability Group 9 that failed to open had lines untwisted by ground impact as shown in the three-photograph-sequence of Figure 34.

The canopy in Permeability Group 10 and one in Group 11 that failed to open also had knots in the suspension lines, which presented complete untwisting similar to those shown in Figures 32 and 33.

The second failure of a canopy from Permeability Group 11 to open was due to a suspension line over the canopy, as is shown in the three-photograph-sequence of Figure 35.

The only failure of a canopy to open that is fully explainable is from Permeability Group 11, which had a suspension line over the canopy. During the other four drop tests in which the canopies failed to open, the failures may have been due to knotted suspension lines. It should be noted, however, that in some instances canopies did open even though the suspension lines never did fully untwist or did not untwist until shortly before ground impact. There was no recorded damage to any of the canopies during the drop tests from aircraft.

Twisted-Line Tests at Release Velocities of 150 and 225 Knots

Twenty-four drop tests were conducted in which parachutes were released from aircraft flying at 150 knots and 23 more tests were conducted in which parachutes were released from aircraft flying at 225 knots. These tests and test results are listed in Tables 5 and 6. The results obtained from these drop tests substantiated the trend of increasing opening time with increasing cloth permeability, as shown in Figures 36 and 37. Canopies were not available for testing from all the permeability groups, and in some cases only one canopy of a particular permeability group was available. With so few test points and a large degree of variation in the test data, no qualitative evaluation of opening times for specific release velocities or cloth permeability of canopies can be made.

TABLE 5

RESULTS OF TWISTED-LINE TESTS WHERE PARACHUTES WERE
RELEASED FROM AIRCRAFT AT VELOCITIES OF 150 KNOTS

Canopy No.	Serial No. of Canopy	Porosity Group	Test No.	Opening Time (sec.)	Untwist Time (sec.)	Down Time (sec.)	Remarks
1	556	I	59-86			7.0	failed to open
6	506	III	59-93	4.5	3.6	13.9	
13	507	III	59-122	2.9	4.2	18.7	
12	508	III	59-88	3.0	4.0	17.0	
17	510	IV	59-123	2.6	4.8	21.4	
19	549	IV	59-124	3.4	2.6	17.2	
19	549	IV	59-980	4.1	5.5	15.6	
21	543	IV	59-84	3.4	3.7	13.8	
24	525	V	59-90	5.6	6.2	11.8	
28	527	VI	59-981	3.2	7.0	16.9	
28	527	VI	59-125	2.8	2.8	18.2	
32	591	VI	59-87	2.7	3.7	16.4	
34	536	VII	59-662	2.4	4.9	15.8	
34	536	VII	59-689	2.5	3.4	14.3	
35	537	VII	59-419	3.1	2.8	16.8	
36	596	VII	59-421	4.0	8.0	15.5	
42	561	VIII	59-85	2.5	8.2	18.4	
43	562	VIII	59-91	4.2	3.2	19.6	
44	565	IX	59-95	3.4	5.5	14.7	
45	577	IX	59-94	2.9		18.6	
47	573	X	59-982	4.2	0	16.3	
50	677	XI	59-87	3.4	4.6	15.2	
49	684	XI	59-92	5.6		12.0	
49	684	XI	59-420			7.3	failed to open

TABLE 6

RESULTS OF TWISTED-LINE TESTS WHERE PARACHUTES WERE
RELEASED FROM AIRCRAFT AT VELOCITIES OF 225 KNOTS

Canopy No.	Serial No. of Canopy	Porosity Group	Test No.	Opening Time (sec.)	Untwist Time (sec.)	Down Time (sec.)	Remarks
1	556	I	59-114	1.0		18.2	
6	506	III	59-425	1.6	10.0	14.2	
13	507	III	59-424	1.9	9.0	15.0	
12	508	III	59-116	2.1	7.3	19.1	
17	510	IV	59-422	1.3		16.5	
21	543	IV	59-112	2.2	8.8	16.4	

TABLE 6 (Continued)

Canopy No.	Serial No. of Canopy	Porosity Group	Test No.	Opening Time (sec.)	Untwist Time (sec.)	Down Time (sec.)	Remarks
19	549	IV	59-96			7.0	failed to open
24	525	V	59-118	2.8	7.9	15.9	
28	527	VI	59-97	4.2		12	
32	591	VI	59-115	4.2	3.0	15.0	
34	536	VII	59-423	1.7	1.8	13.5	
34	536	VII	59-452	1.8		16.0	
35	537	VII	59-454	2.5		15.6	
36	596	VII	59-453	1.6	10.0	18.4	
42	561	VIII	59-113			7.1	
41	560	VIII	60-1258	3.0		18.3	failed to open (photo of suspension lines knotted)
43	562	VIII	59-119	4.6	1.5	12.0	
44	565	IX	59-121	2.0	11.2	15.7	
45	577	IX	59-120	7.0		10.5	
48	679	X	60-1257	3.0		20.2	
50	677	XI	59-117	3.0	8.2	13.5	
49	684	XI	59-663	5.1	3.4	13.2	
49	684	XI	59-668			6.1	
							failed to open (photos of twisted suspension lines)

Of the 24 drops conducted at release velocities of 150 knots, two failures occurred in which canopies failed to open. One failure occurred in the lowest group and one in the highest permeability group. The failure that occurred in Group 1 was caused by suspension lines that were twisted and knotted at the midpoint. The parachute canopy that failed to open in Permeability Group 11 was slowly untwisting and was nearly inflated at the time of ground impact.

Out of a total of 23 tests, three failures occurred during the 225-knot drop tests. One failure each occurred in Permeability Groups 4, 8, and 11. The failures in Groups 8 and 11 can be explained in part by Figures 38 and 39, which show the entanglement in the suspension lines.

SPECIAL TESTS

Comparative Drop Tests from Whirl Tower and from Aircraft

Seven special-instrumented drop tests were conducted, three from aircraft and four from the whirl tower, to determine if forces experienced at line stretch and opening were of the same magnitude for nearly identical test conditions, utilizing these two different test methods. All tests were conducted with only one canopy (Serial No. 322520) from Permeability Group 6. The release velocity was 150 knots in each case and there were no twisted lines.

The snatch force experienced by the parachute during tests from the whirl tower varied from 980 to 1740 pounds as shown in Figure 40 with an average snatch force of 1400 pounds. The snatch force encountered during drops from aircraft varied from 1320 to 1700 pounds with an average snatch force of 1500 pounds. The snatch forces measured are of the same order of magnitude for both types of drops.

The opening forces of the canopy that were obtained during the drop tests from the whirl tower and from aircraft were also of the same order of magnitude, as seen from Figure 40. The average opening force for the drops from aircraft was 1950 pounds and from the whirl tower 1860 pounds.

The snatch and opening forces of the parachute canopies that were experienced during tests utilizing both methods of drop testing were nearly identical, and the forces measured during the drops from aircraft were within the limits of the forces that occurred on the whirl-tower tests.

Air Permeability of Cloth

The air permeability or porosity of parachute cloth is conventionally expressed as the volumetric flow of air through a unit area of cloth at a specified differential pressure, usually 1/2-inch water and at sea level conditions.

Air permeability readings of the canopy cloth were taken in a marked area of each section of each canopy before the particular canopy was packed for the drop test. Permeability readings were taken again in the same areas after the canopy had been subjected to drop test.

A graphical presentation of average air permeability values measured throughout the canopy for all available canopies are shown in Figure 41. Plotted points represent values measured after manufacture in 1947, values measured prior to initiation of drop testing in 1959, and values measured after the completion of the drop test program. As can be seen from Figure 42, the cloth permeability had increased during the time period 1947-1959 for all permeability groups; however, representative test results presented in Reference 1 indicate changes in permeability are primarily due to the test conducted in 1947. The greater percentage increase occurred in the lower permeability groups. After all testing was completed, the average values of cloth permeability for all permeability groups were generally lower than those determined prior to the initiation of the drop test program. As is evident from Figure 43, the average cloth permeabilities for the lower permeability groups were still higher after the completion of drop testing than in 1947. In the medium (range of nominal permeabilities) and high permeability groups, the average cloth permeability values measured approached closely those determined in 1947.

The change in average cloth permeability in a given parachute canopy after each drop test was determined to be quite erratic. In general, however, a trend of decreasing average cloth permeability as a function of number of canopy deployments can be detected. The change of average cloth permeability with number of canopy deployments for parachute canopies in the different permeability groups is shown in Figure 44.

CONCLUSIONS

An experimental test program was conducted to validate the original test results under actual operational conditions and to determine the effects of aging upon the cloth permeability and the opening characteristics of 24-foot diameter textile parachute canopies. These parachute canopies were manufactured in 1947 and subjected to cloth permeability and drop tests at that time. After a storage period of 12 years, additional cloth permeability, twisted line, and strength tests were conducted. As a result of this investigation, the following conclusions can be reached:

1. No essential differences in the opening characteristics of parachutes could be attributed to the change in whirl-tower testing method, which is described under Tests and Deployment Methods.
2. A slight increase in cloth permeability values, particularly in the lower permeability range (50-110 $\text{ft}^3/\text{ft}^2/\text{min}$) was measured at the end of the 12-year storage period; however, these increases in cloth permeability may have occurred during the drop testing in 1947.
3. Opening forces of the canopies and opening times measured compared closely with those obtained during the initial test program conducted in 1947.
4. As expected, opening forces of the canopies decreased with increasing cloth permeability under identical test conditions. Conversely, filling times increased with increasing cloth permeability. This trend also held for canopies deployed under twisted-line conditions.
5. No opening failures were experienced with canopies fabricated from cloth with high air permeability, although the variation in opening time and opening force (for identical test conditions) increased as the cloth permeability increased. This same trend was observed on canopies deployed under twisted-line conditions.
6. One hundred and seventy-six whirl-tower tests were conducted at release speeds between 100 and 225 knots. During these tests, only two instances occurred where the canopy failed to open prior to ground impact. In one instance, the canopy had reached 3/4 inflation at ground impact, and the other failure was partially attributed to tangled and knotted suspension lines.
7. The twisted suspension-line tests conducted at release velocities of 110 knots had six canopy-opening failures in 101 tests. Four of the canopies that failed to open were of very high permeability. If packing errors can be disregarded, the two opening failures that occurred in the normal permeability range are unexplainable. However, we believe that the canopy-opening failures were caused primarily by suspension lines that became knotted rather than untwisting in the usual manner.

LIST OF REFERENCES

1. Effect of Porosity on Parachute Opening, Memorandum Report MCREXE-672-2A, Headquarters Air Materiel Command, Wright Field, Dayton, Ohio. 31 December 1948.
2. Heinrich, H. G., Some Research Efforts Related to Problems of Aerodynamic Deceleration, WADD Technical Note 60-276, Prepared by University of Minnesota on Contract AF33(616)-6372, Wright Air Development Division, Wright-Patterson AF Base, Ohio. November 1960.
3. Heinrich, H. G., and Haak, E. L., Stability and Drag of Parachutes with Varying Effective Porosity, ASD Technical Documentary Report 62-100, Prepared by University of Minnesota on Contract AF33(616)-8310, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. To be published.
4. Preparation of Fabric and Porosity Tests Made on Completed Parachutes Before, During, and After Drop Testing, Cheney Brothers, Manchester, Connecticut. 24 September 1947.

**APPENDIX
ILLUSTRATIONS**

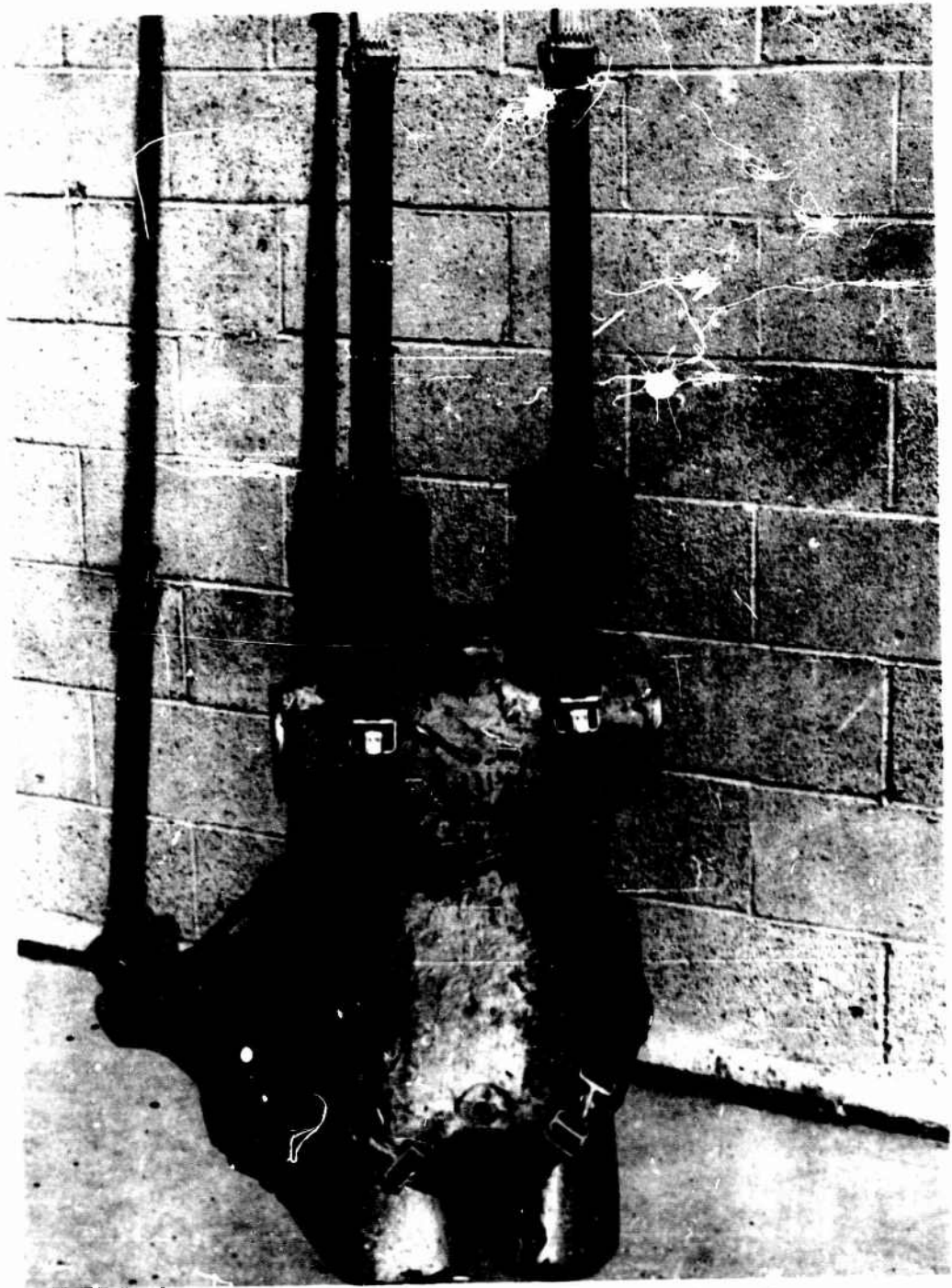


Figure 1. Rubber Torso Dummy with Tensiometers Installed in Canopy Risers



Figure 2. Sideview of B-4 Backpack Installed on Dummy



Figure 3. Backview of B-4 Backpack Installed on Dummy

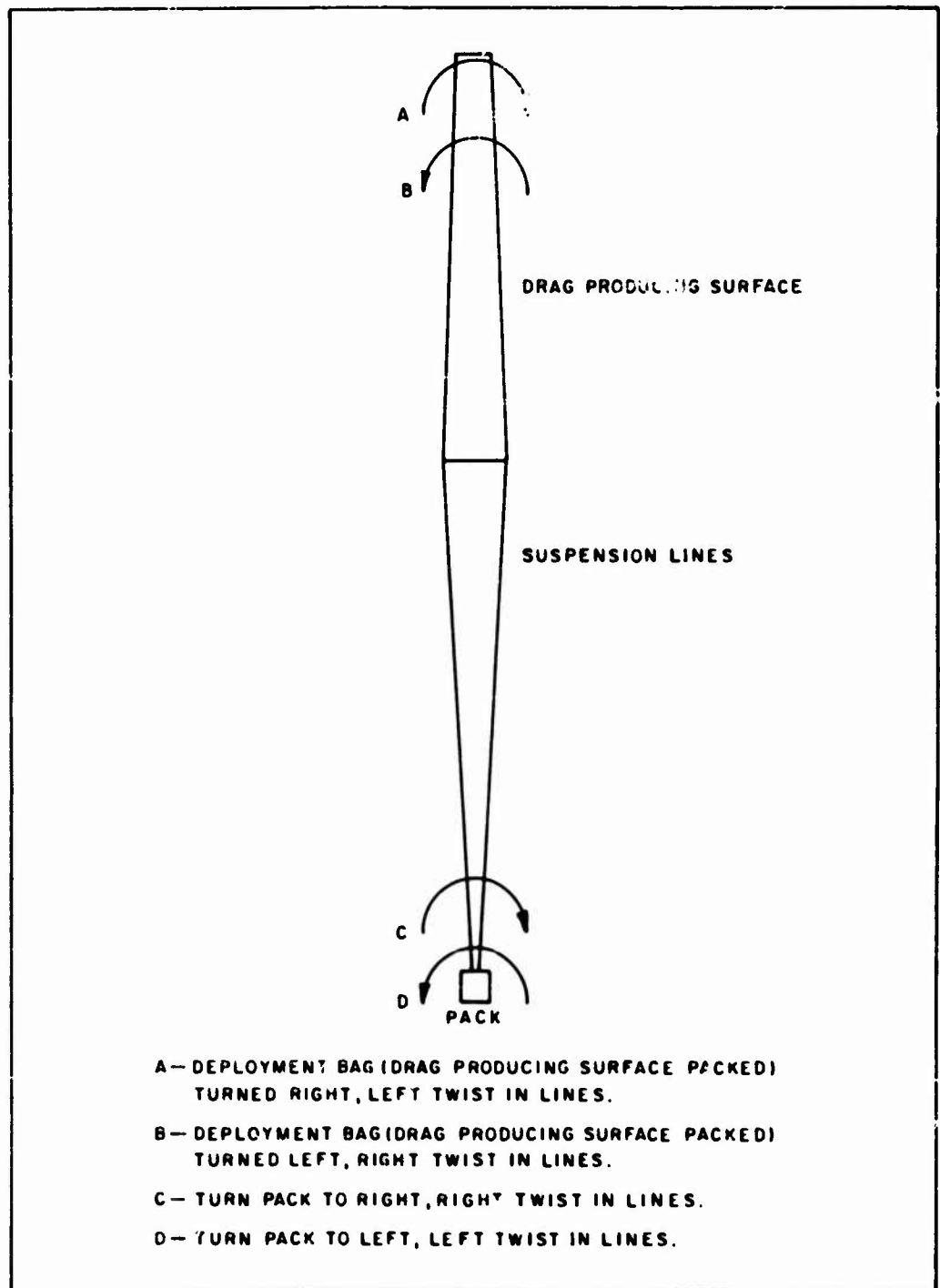


Figure 4. Packing Procedure Incorporating Line Twists

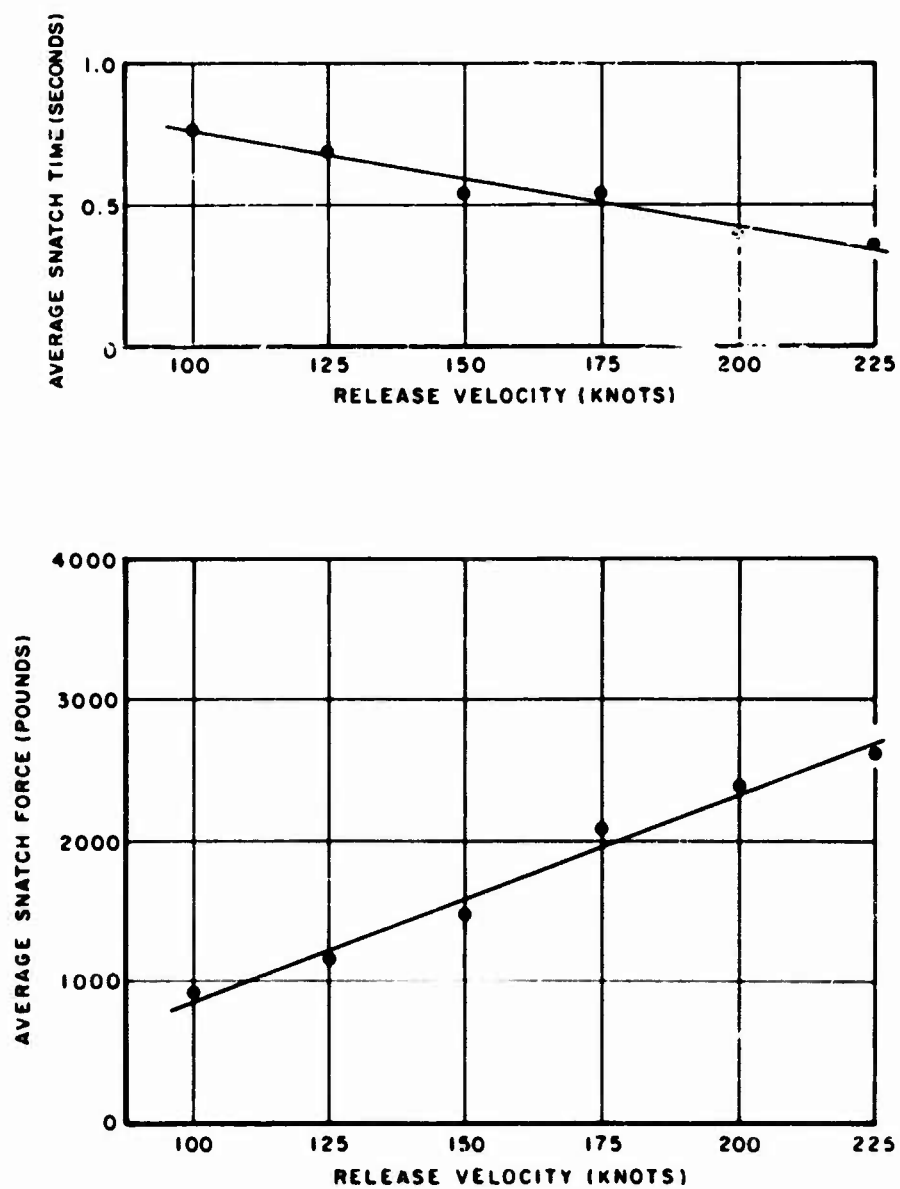


Figure 5. Snatch Force of Parachute Canopy and Time to Snatch Versus Release Velocity (Whirl-Tower Tests)

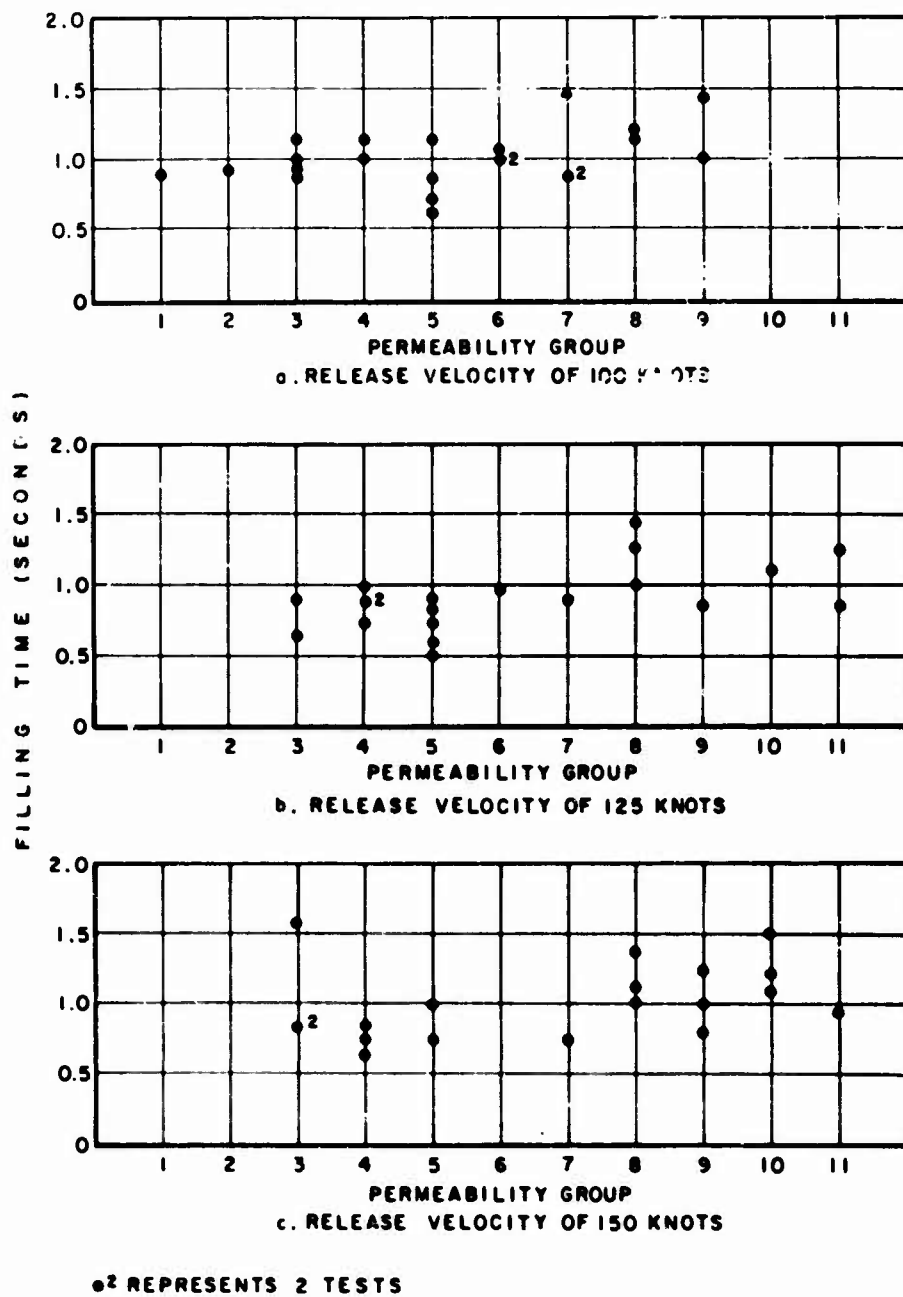


Figure 6. Filling Time of Canopy Versus Cloth Permeability Group for Various Release Velocities (Whirl-Tower Tests)

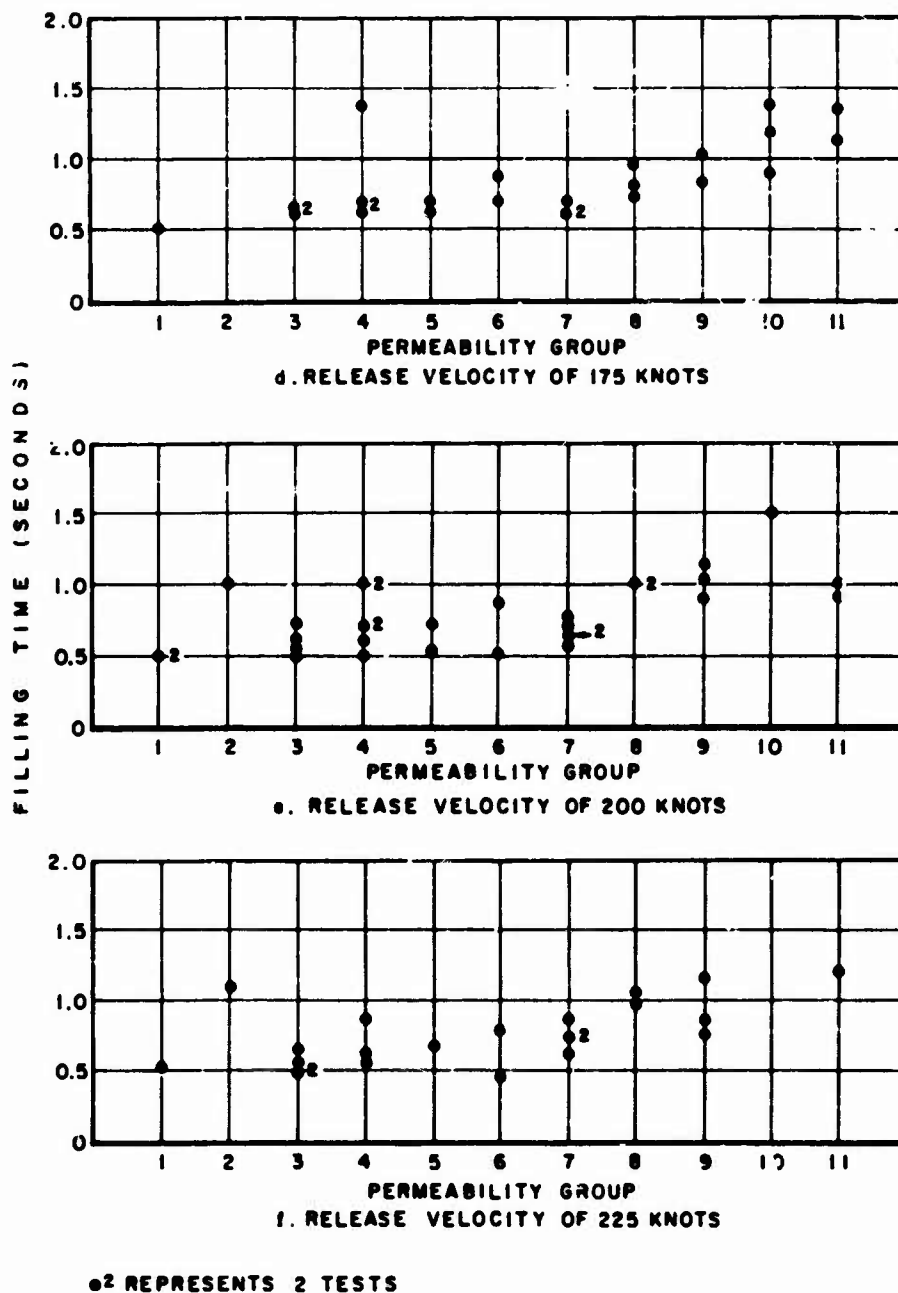
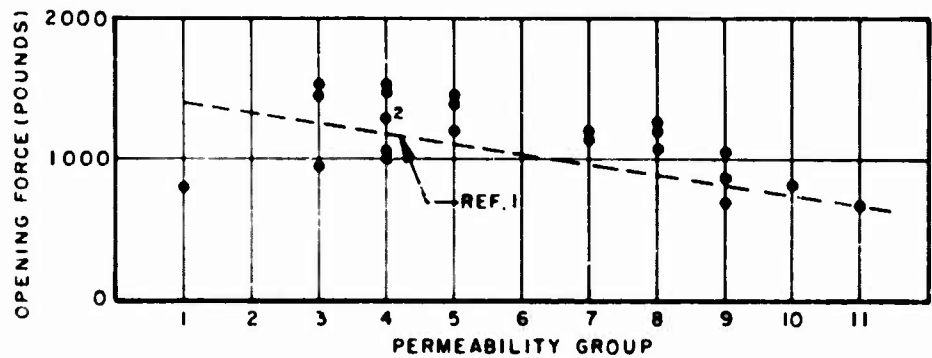
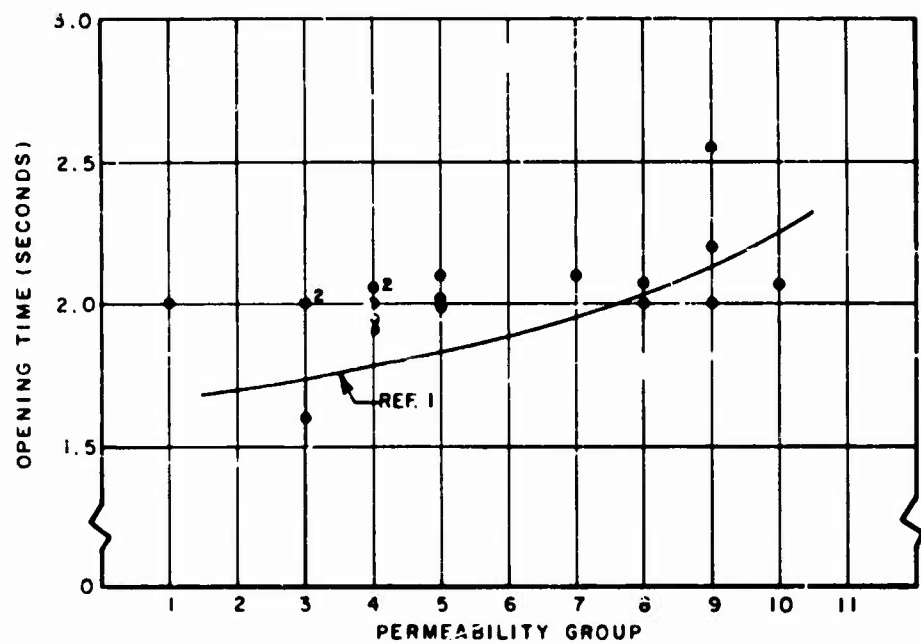
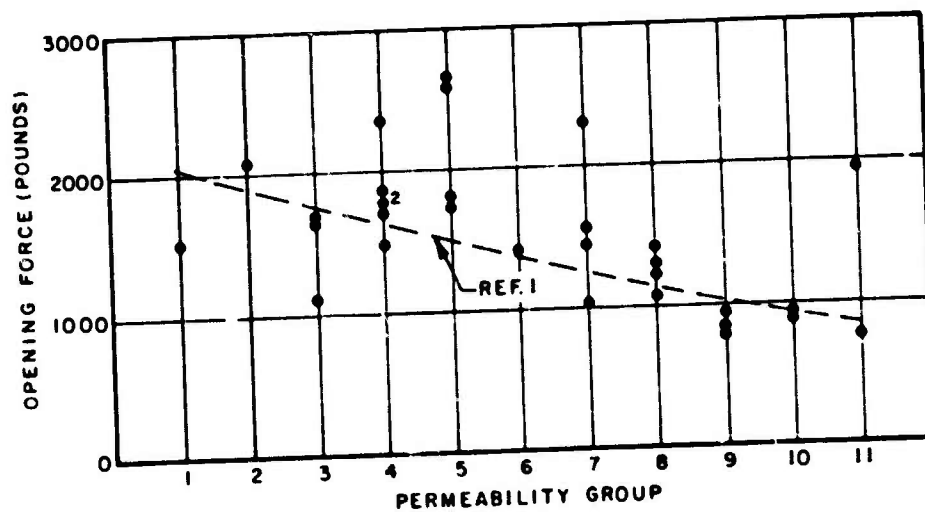
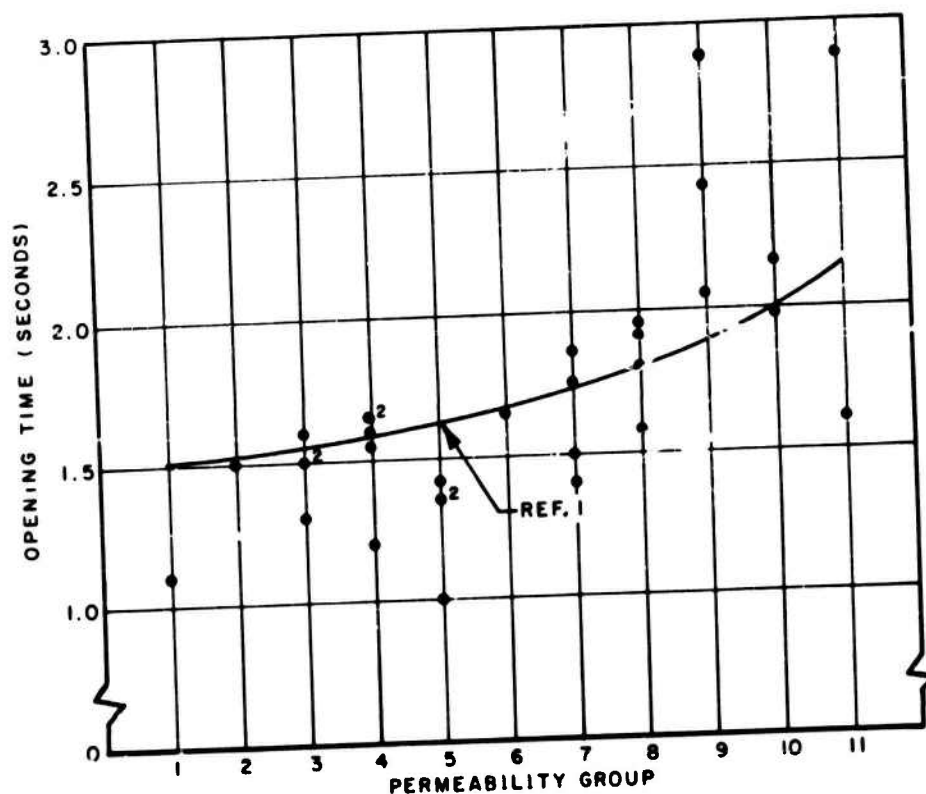


Figure 6 (Cont'd). Filling Time of Canopy Versus Cloth Permeability Group for Various Release Velocities (Whirl-Tower Tests)



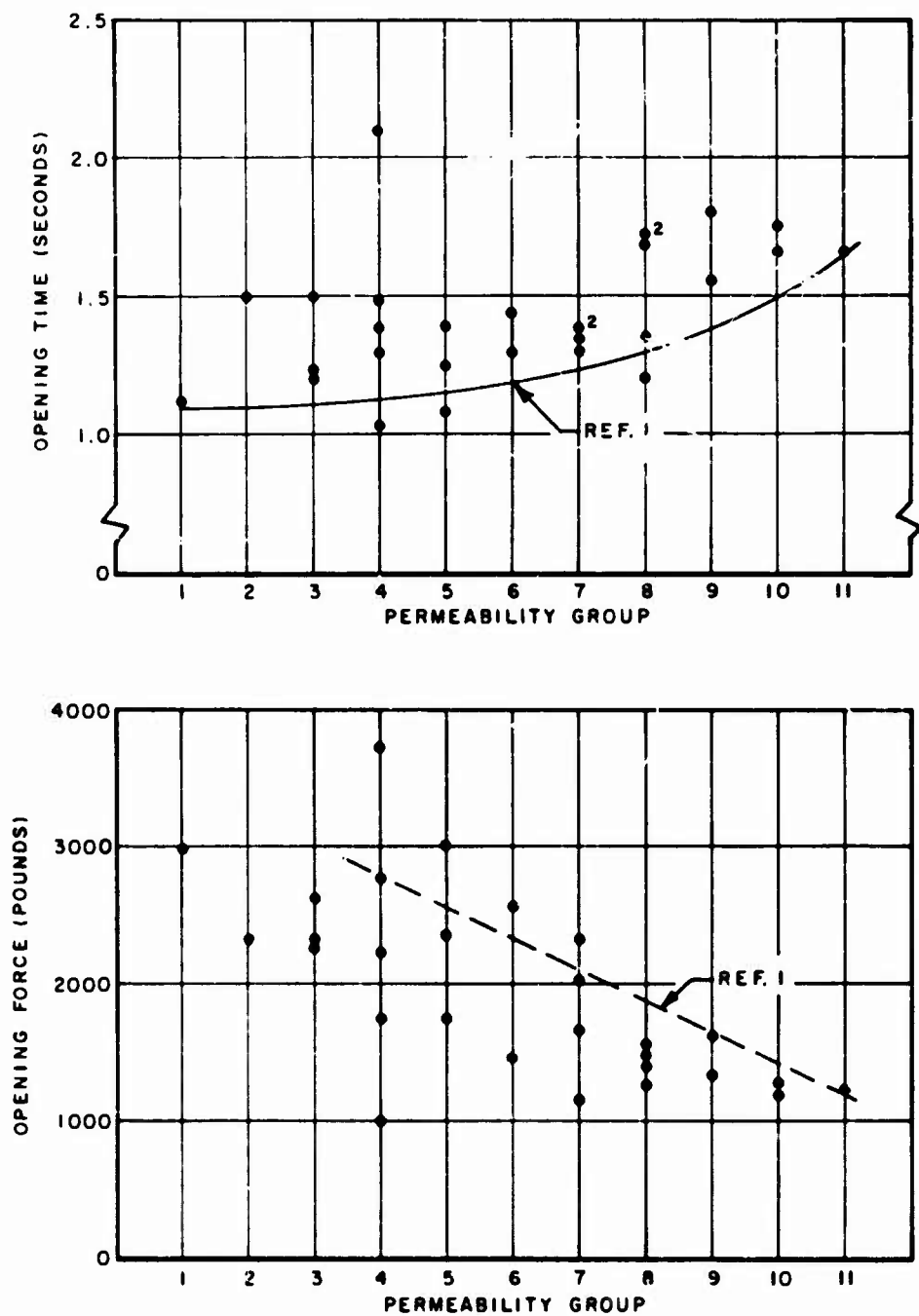
•² REPRESENTS 2 TESTS

Figure 7. Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 100 Knots (Whirl-Tower Tests)



•² REPRESENTS 2 TESTS

Figure 8. Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 125 Knots (Whirl-Tower Tests)



•² REPRESENTS 2 TESTS

Figure 9. Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 150 Knots (Whirl-Tower Tests)

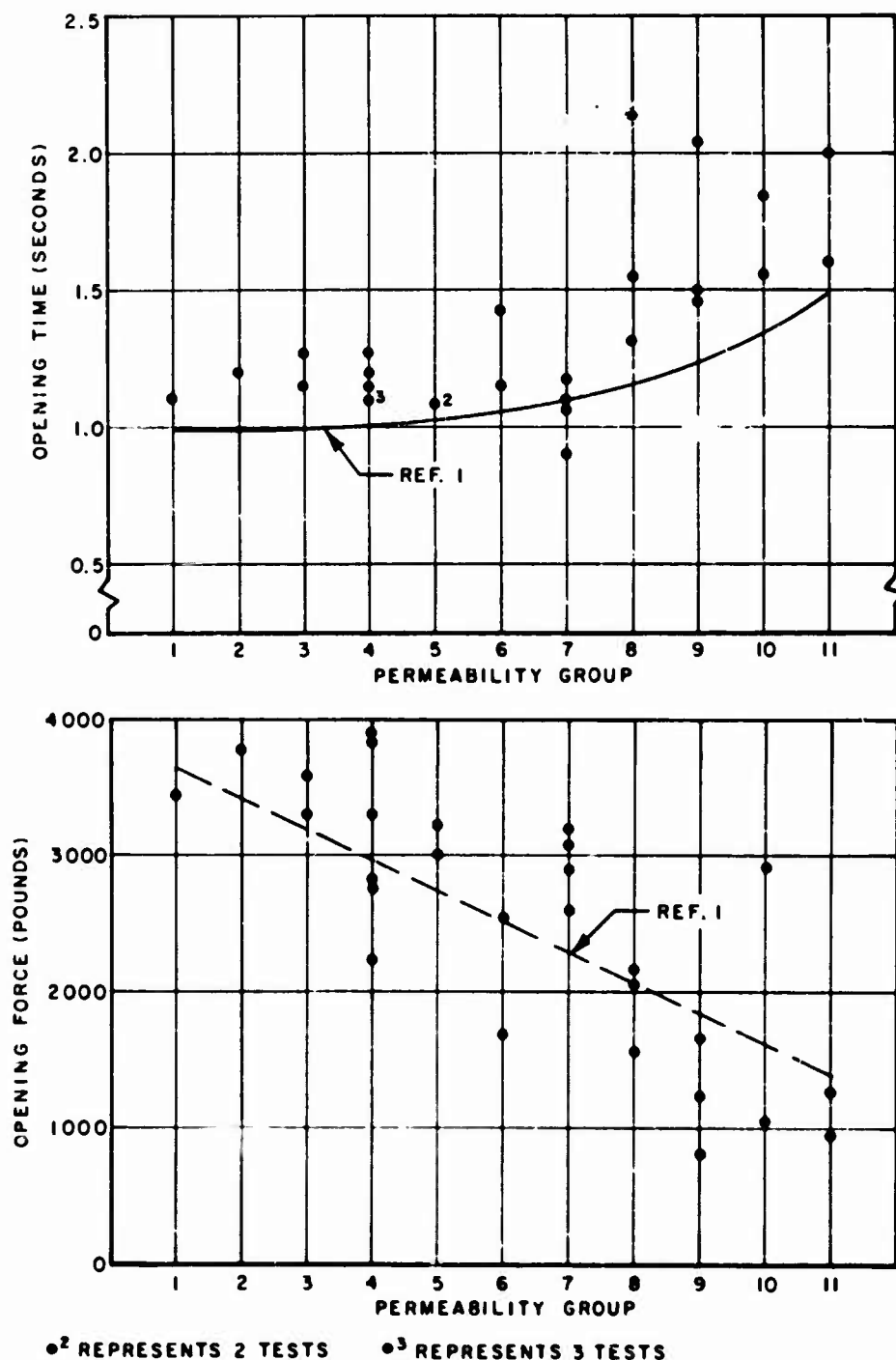


Figure 10. Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 175 Knots (Whirl-Tower Tests)

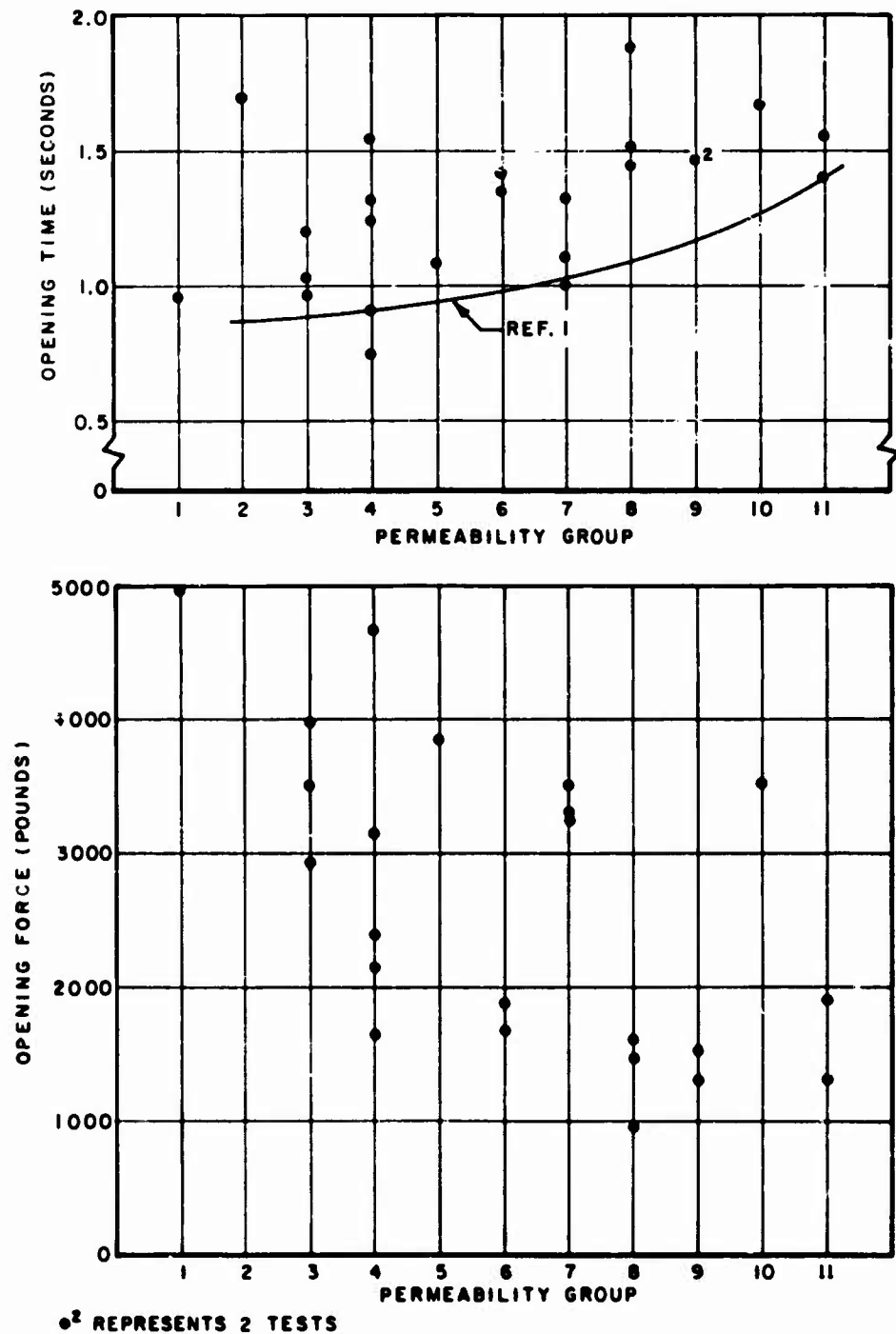


Figure 11. Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 200 Knots (Whirl-Tower Tests)

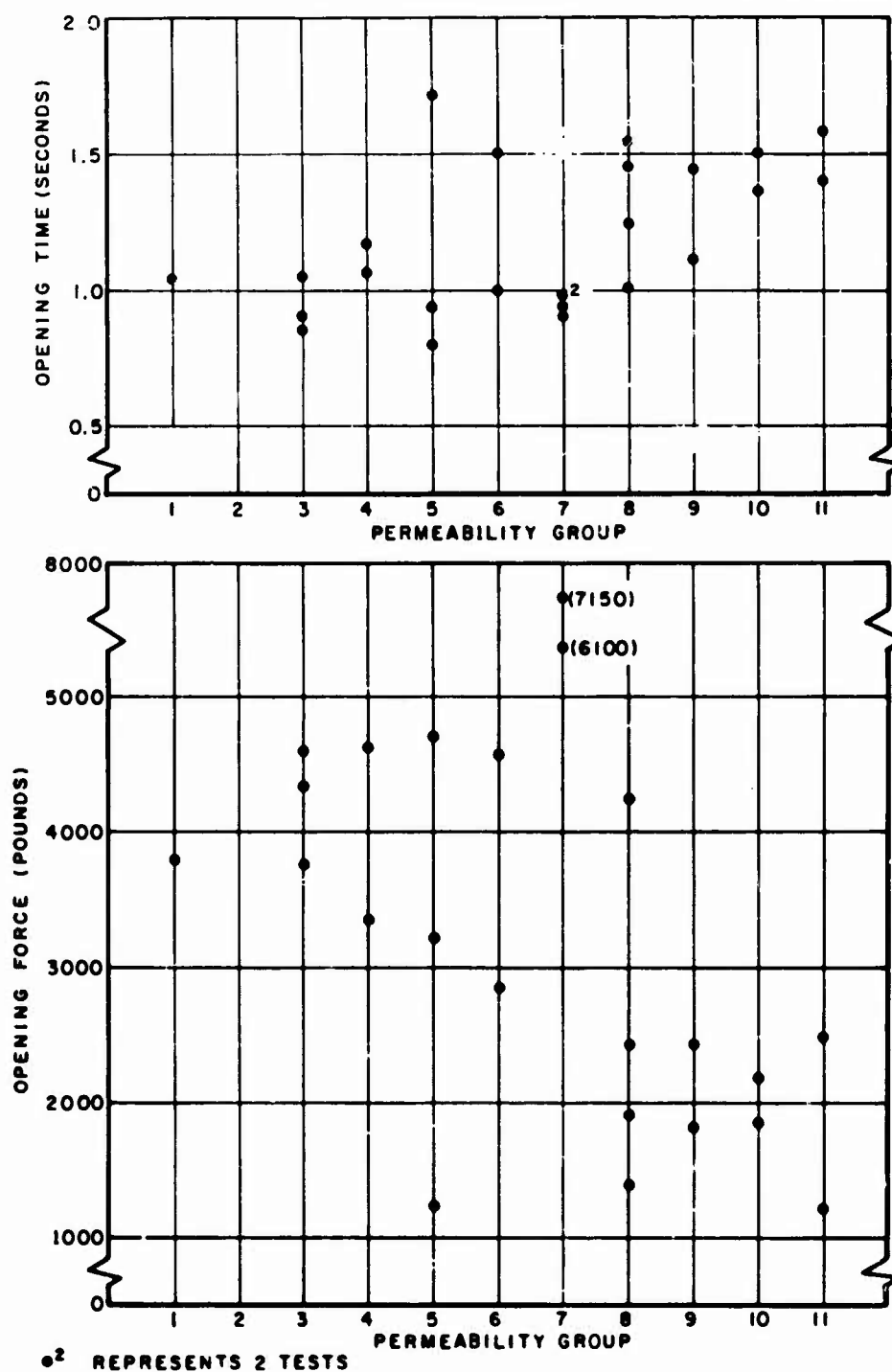


Figure 12. Opening Force and Opening Time Versus Cloth Permeability Group for a Release Velocity of 225 Knots (Whirl-Tower Tests)

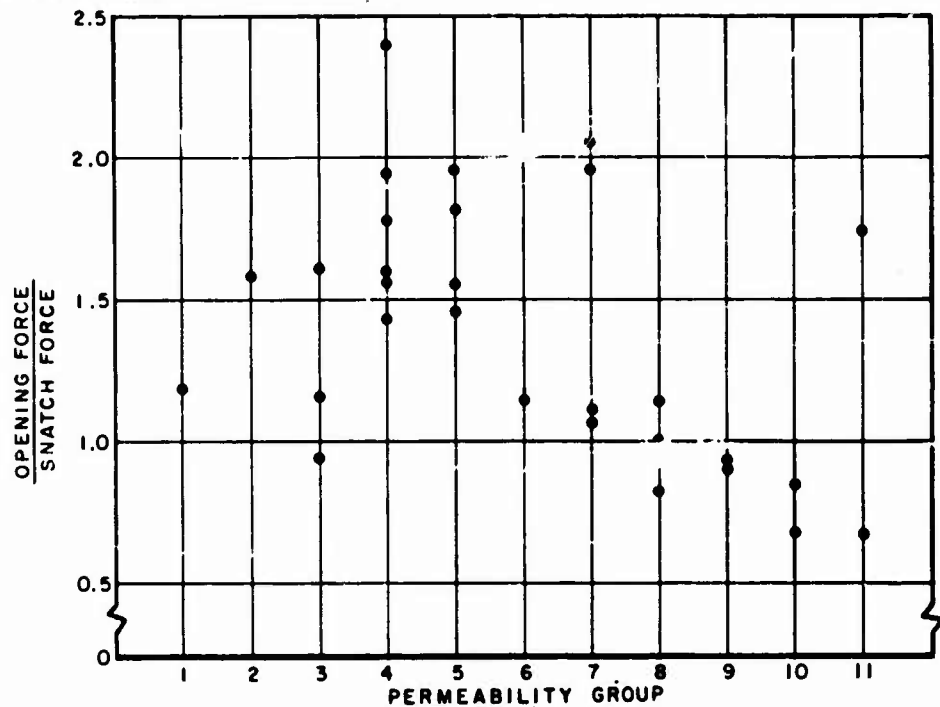


Figure 13. Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 125 Knots (Whirl-Tower Tests)

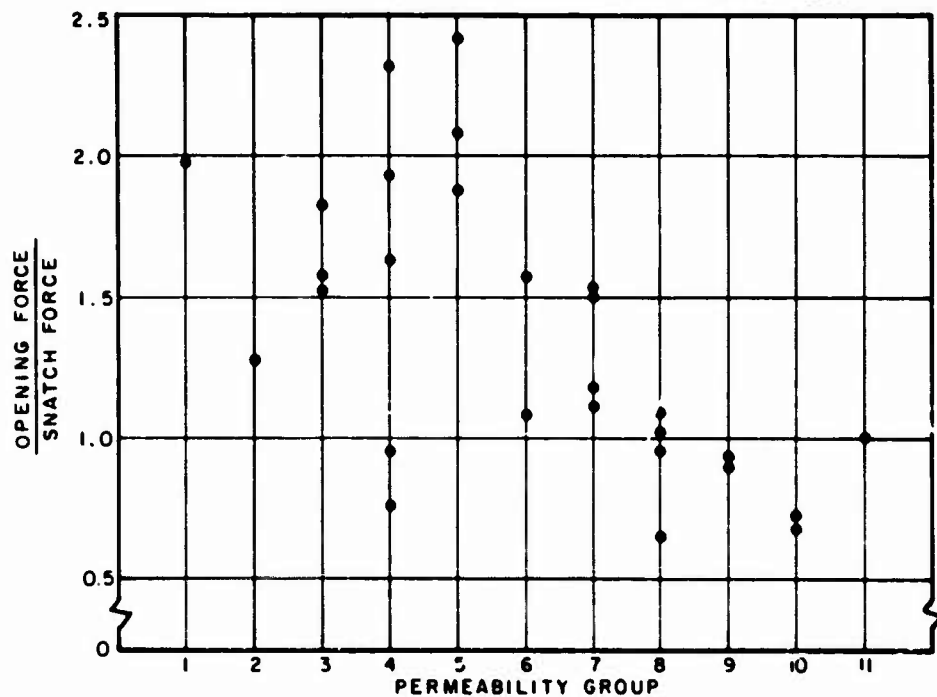
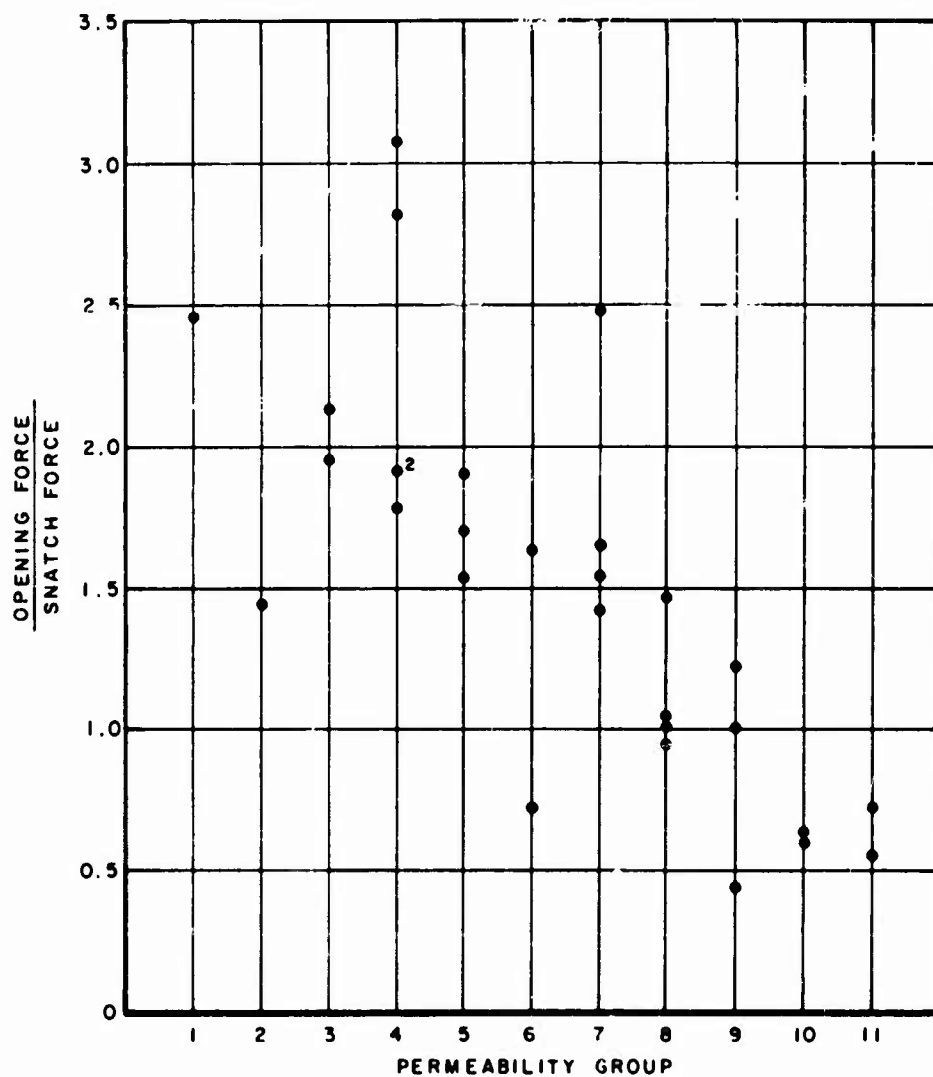


Figure 14. Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 150 Knots (Whirl-Tower Tests)



•² REPRESENTS 2 TESTS

Figure 15. Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 175 Knots (Whirl-Tower Tests)

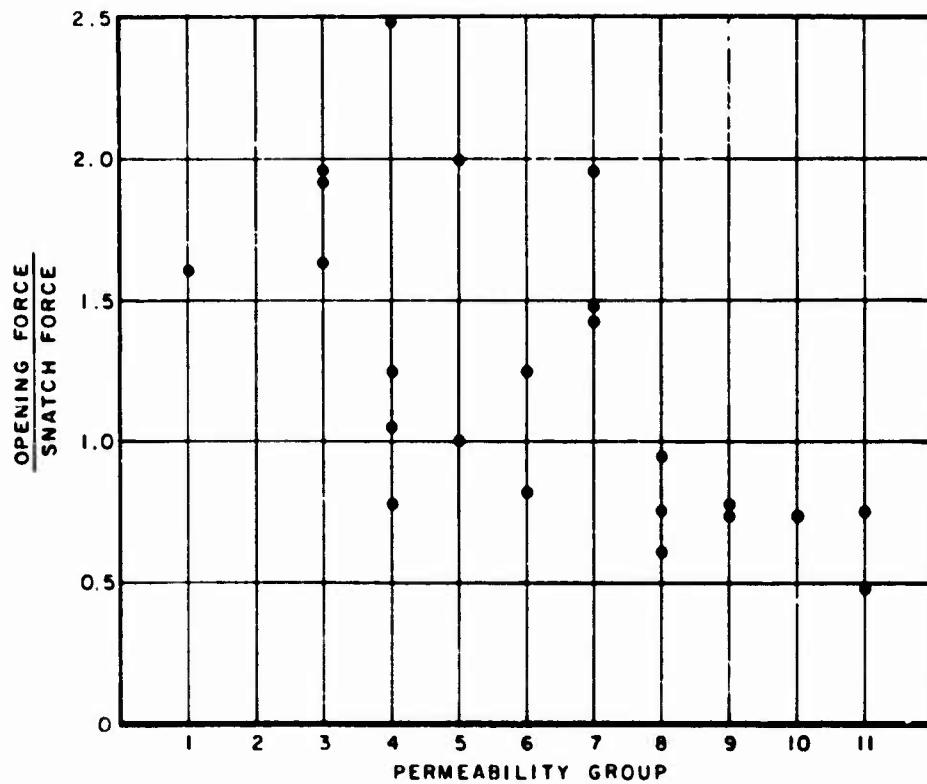


Figure 16. Ratio of Opening Force to Snatch Force Versus Cloth Permeability Group for a Release Velocity of 200 Knots (Whirl-Tower Tests)

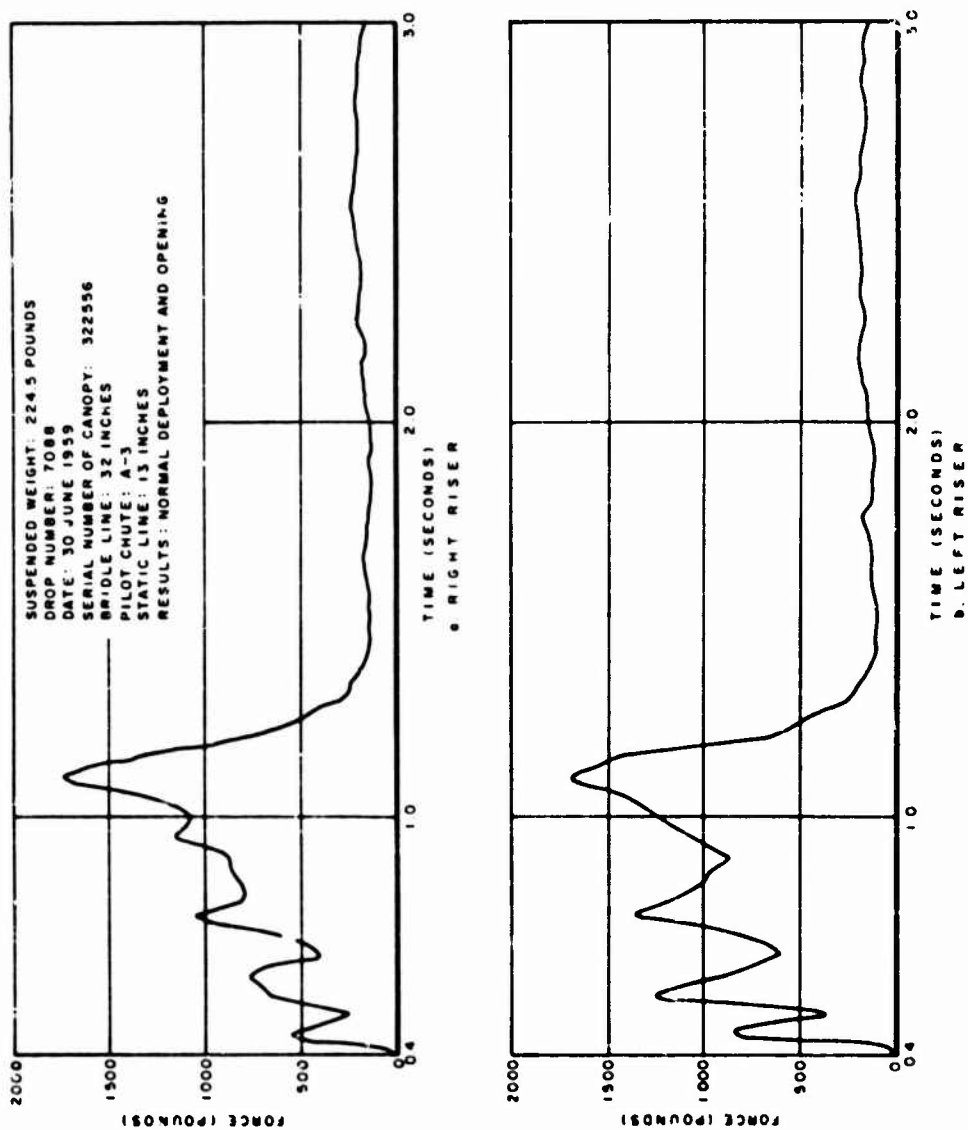


Figure 17. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 1 (Whi-1-Tower Tests)

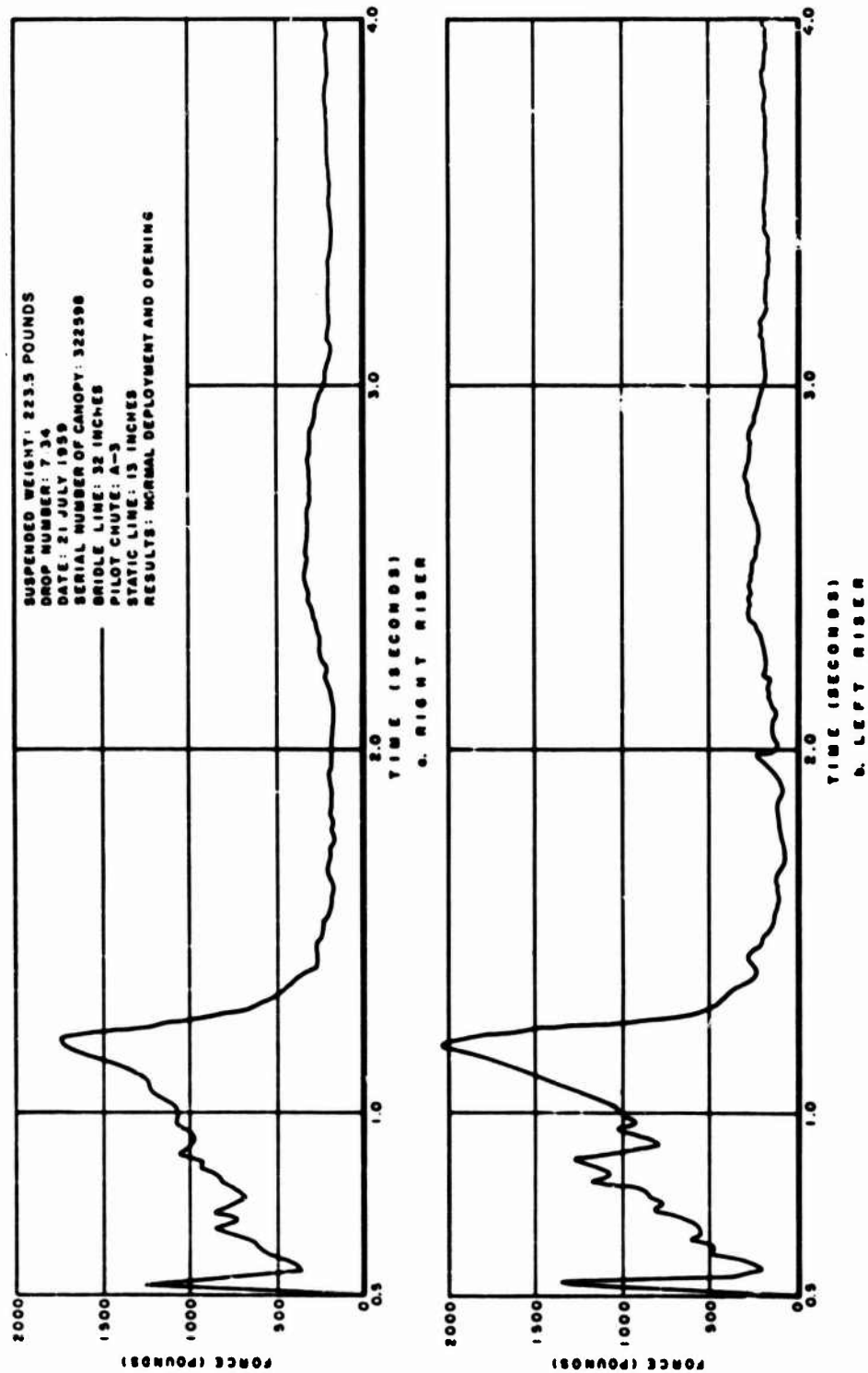


Figure 18. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 2 (Whirl-Tower Tests)

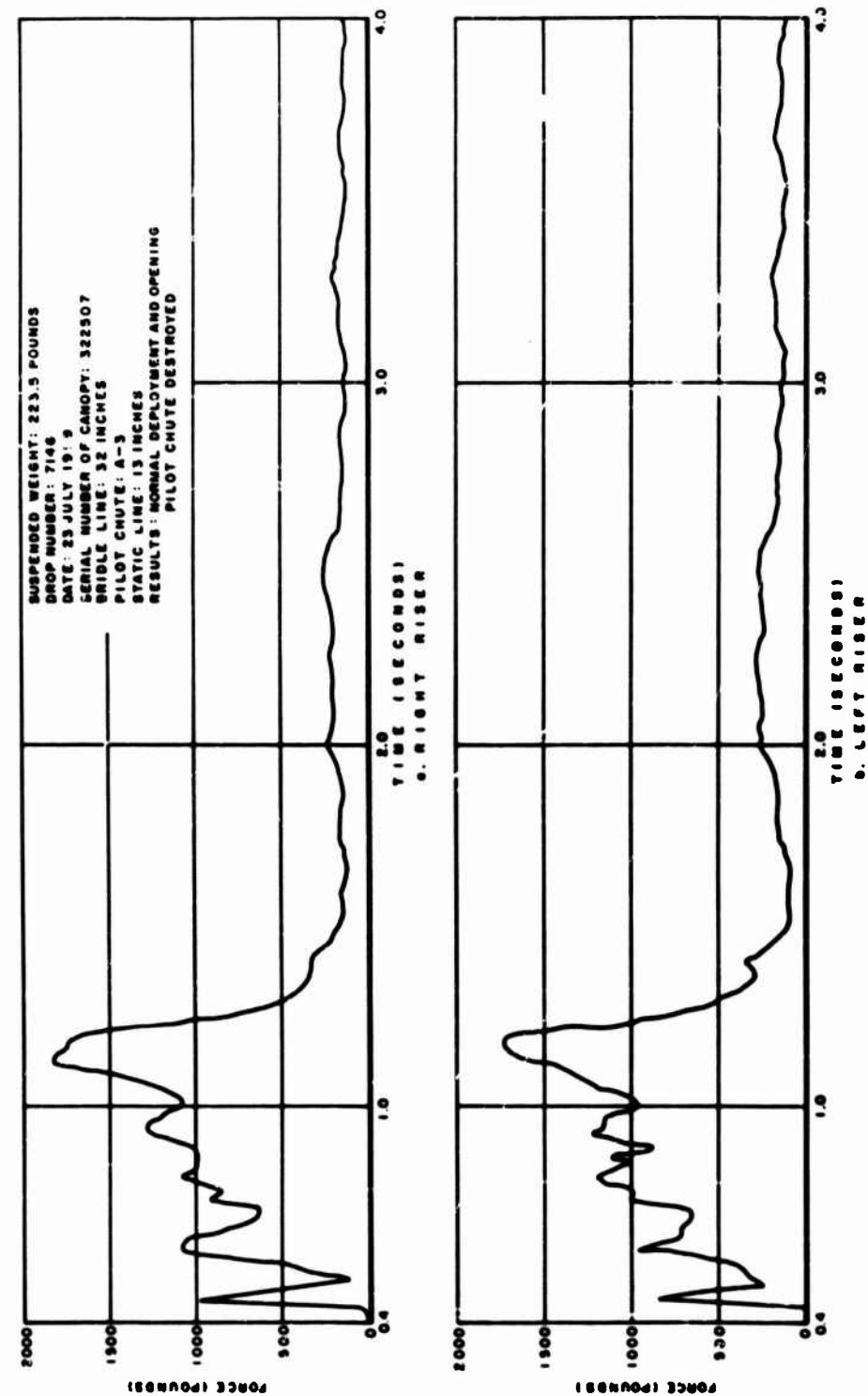


Figure 19. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 3 (Whirl-Tower Tests)

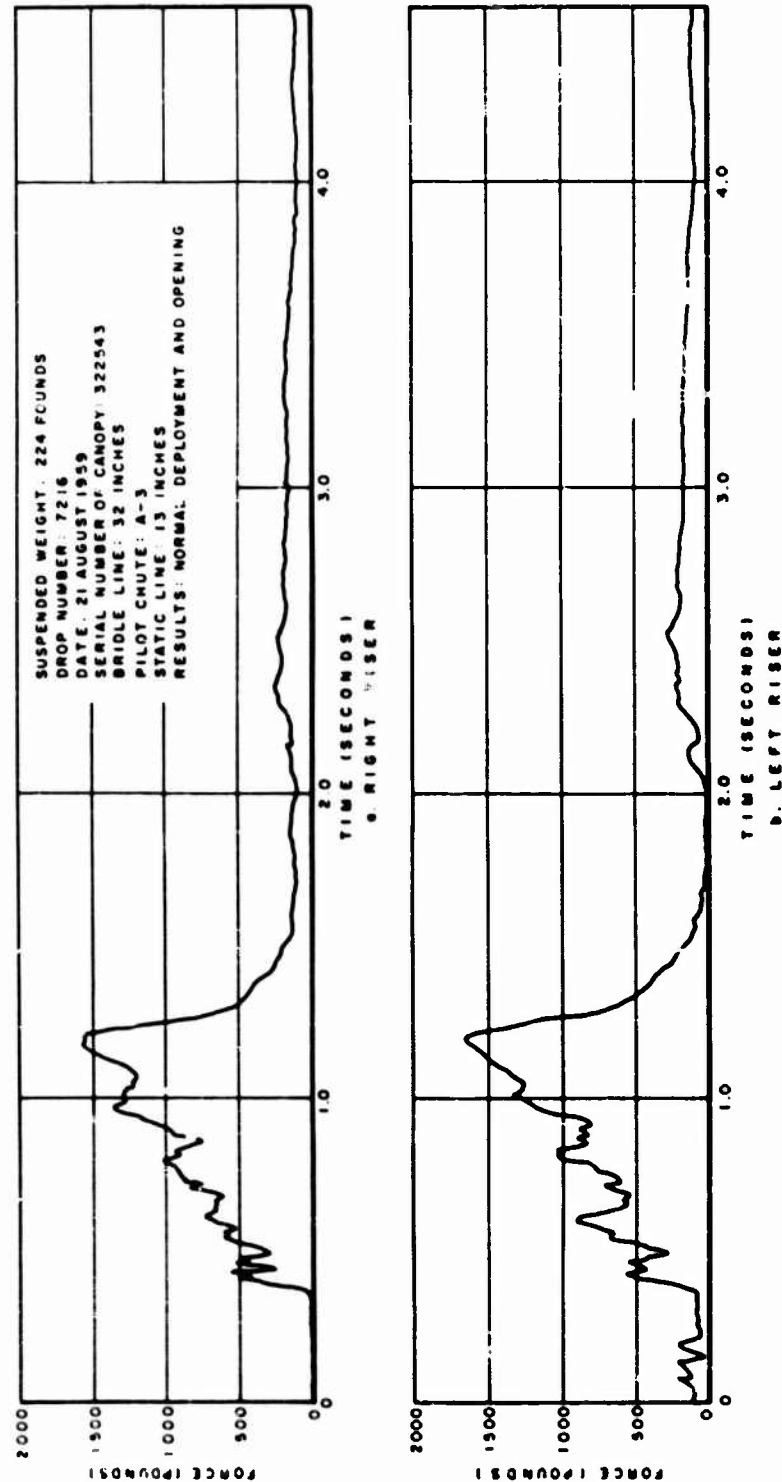


Figure 20. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 4 (Whirl-Tower Tests)

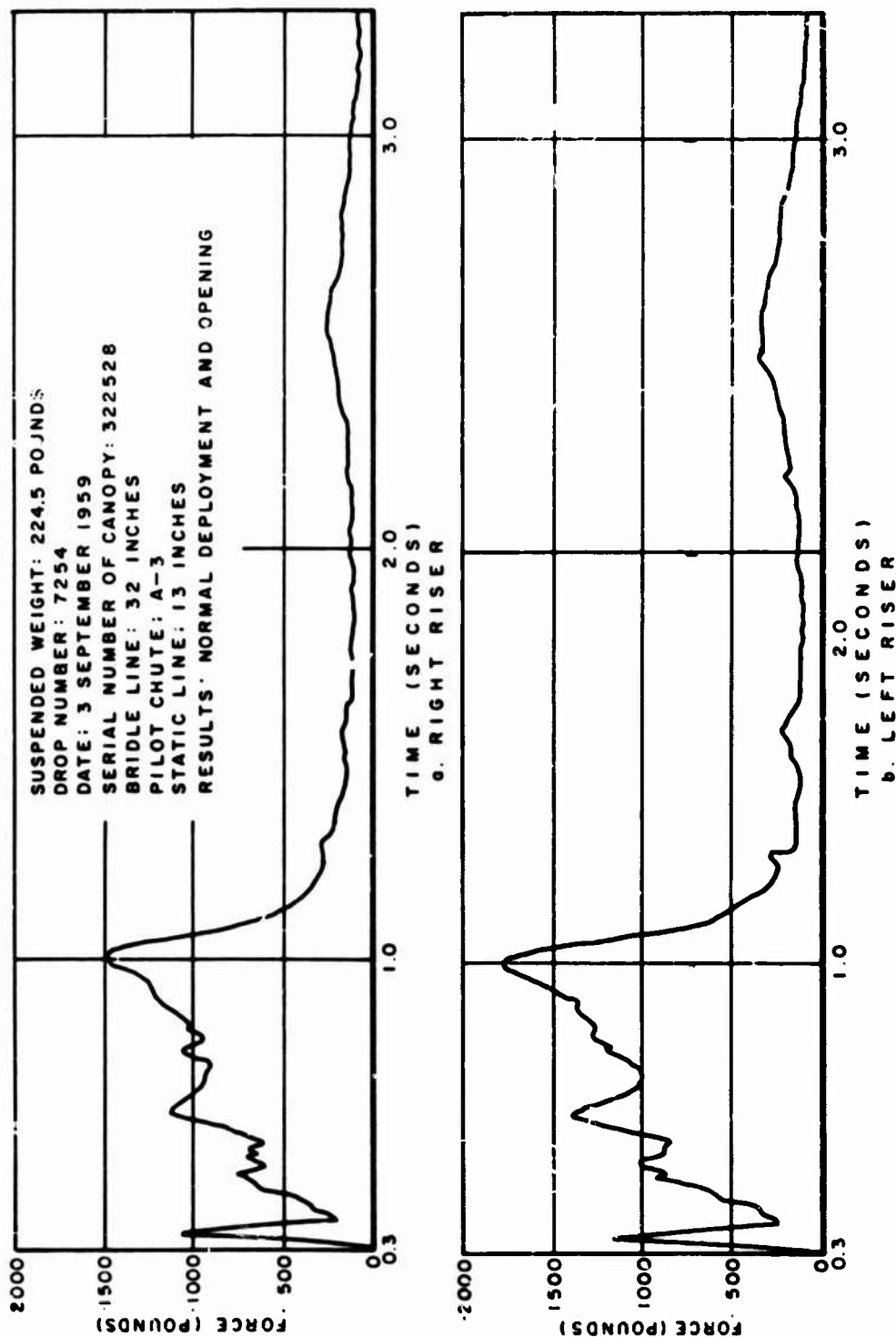


Figure 21. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 5 (Whirl-Tower Tests)

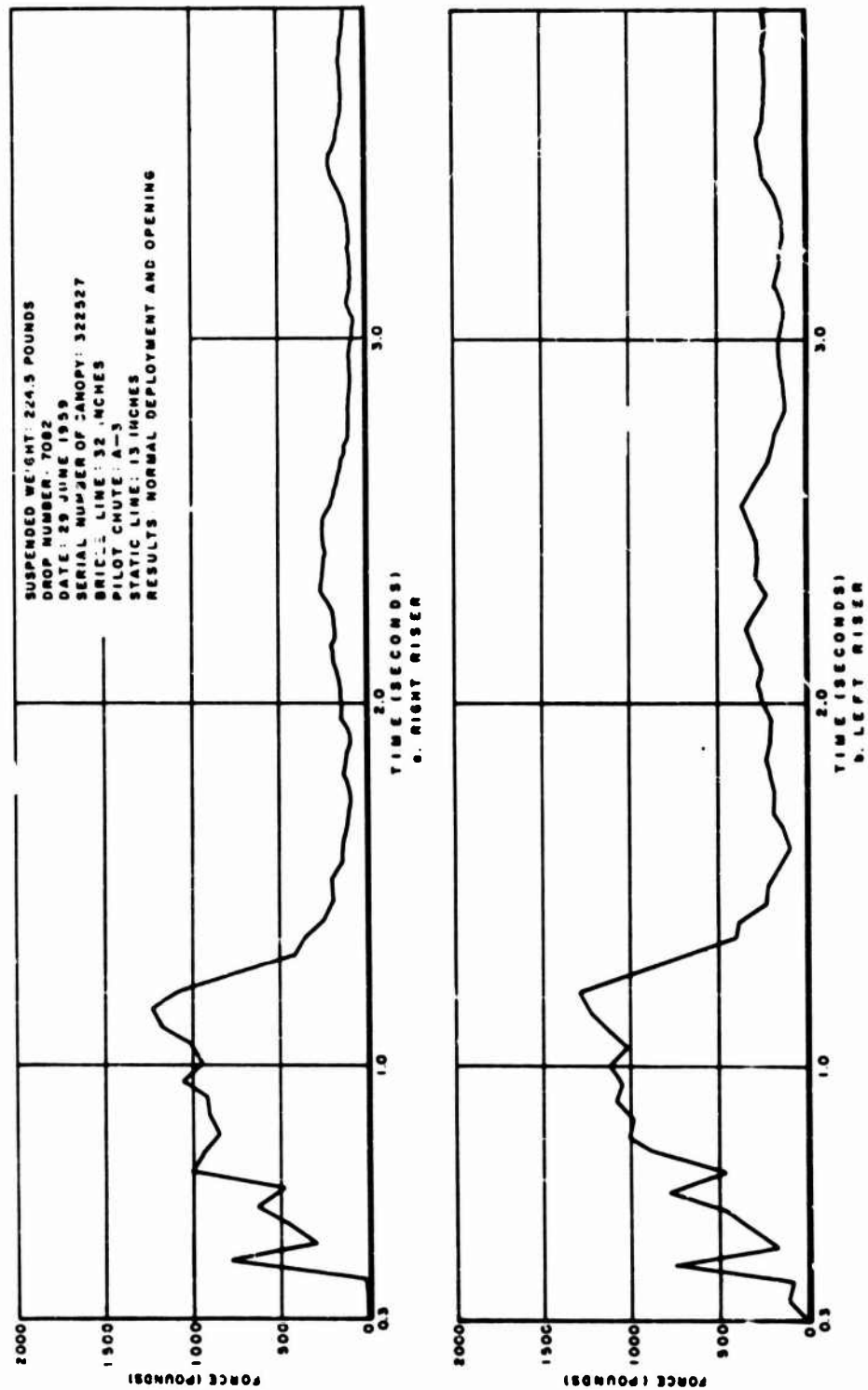


Figure 22. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 6 (Whirl-Tower Tests)

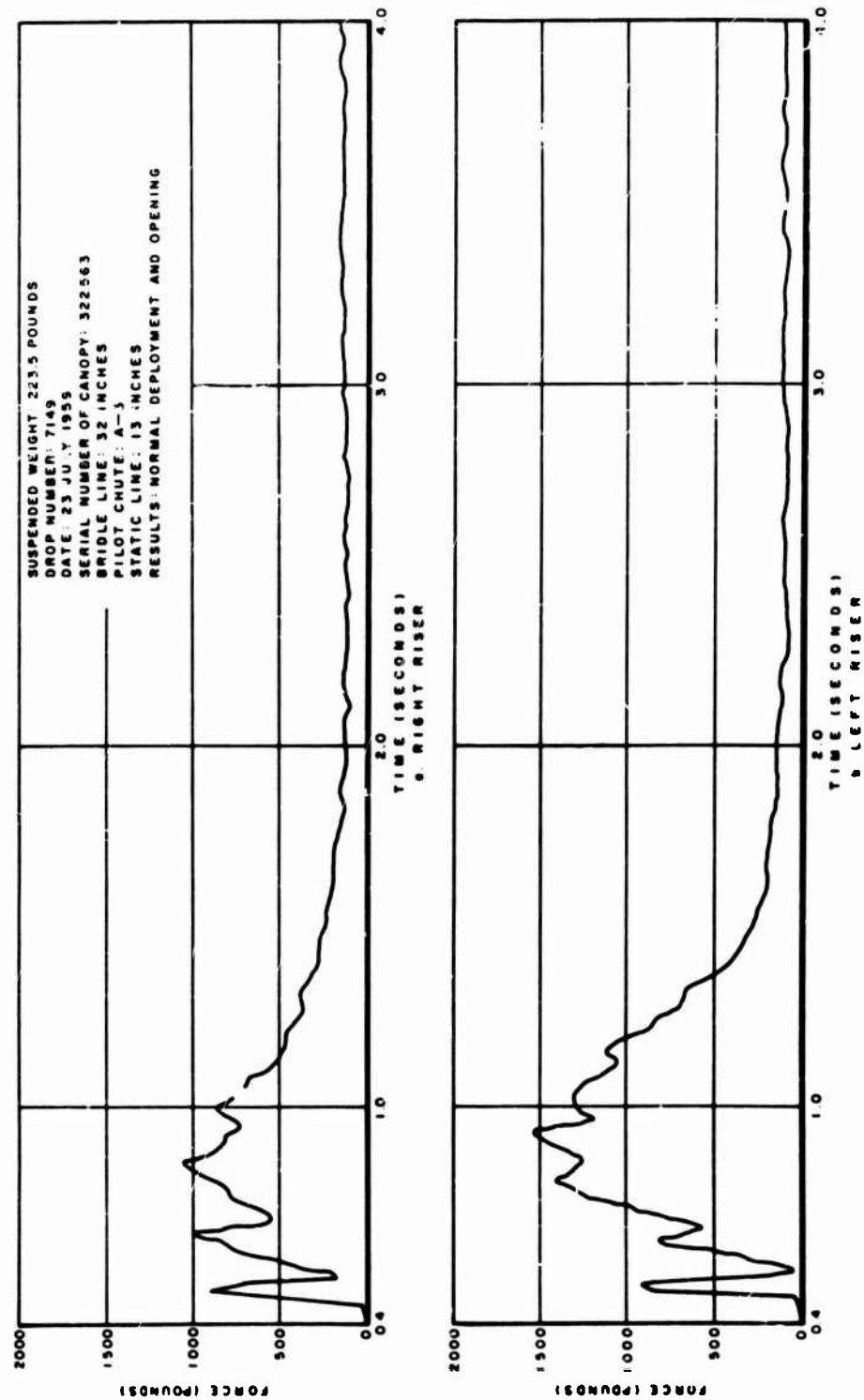


Figure 23. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 7 (Whirl-Tower Tests)

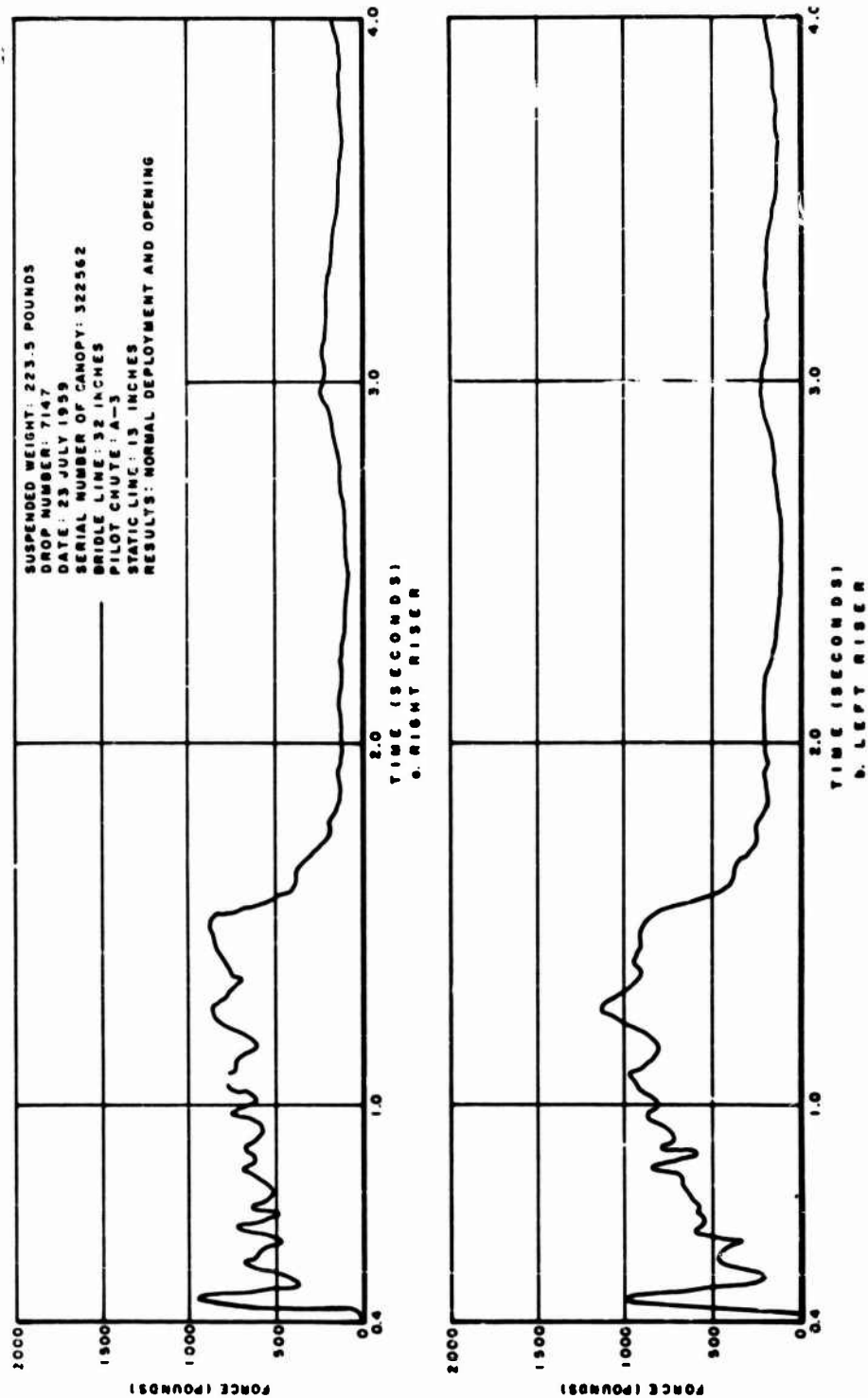


Figure 24. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 8 (Whirl-Tower Tests)

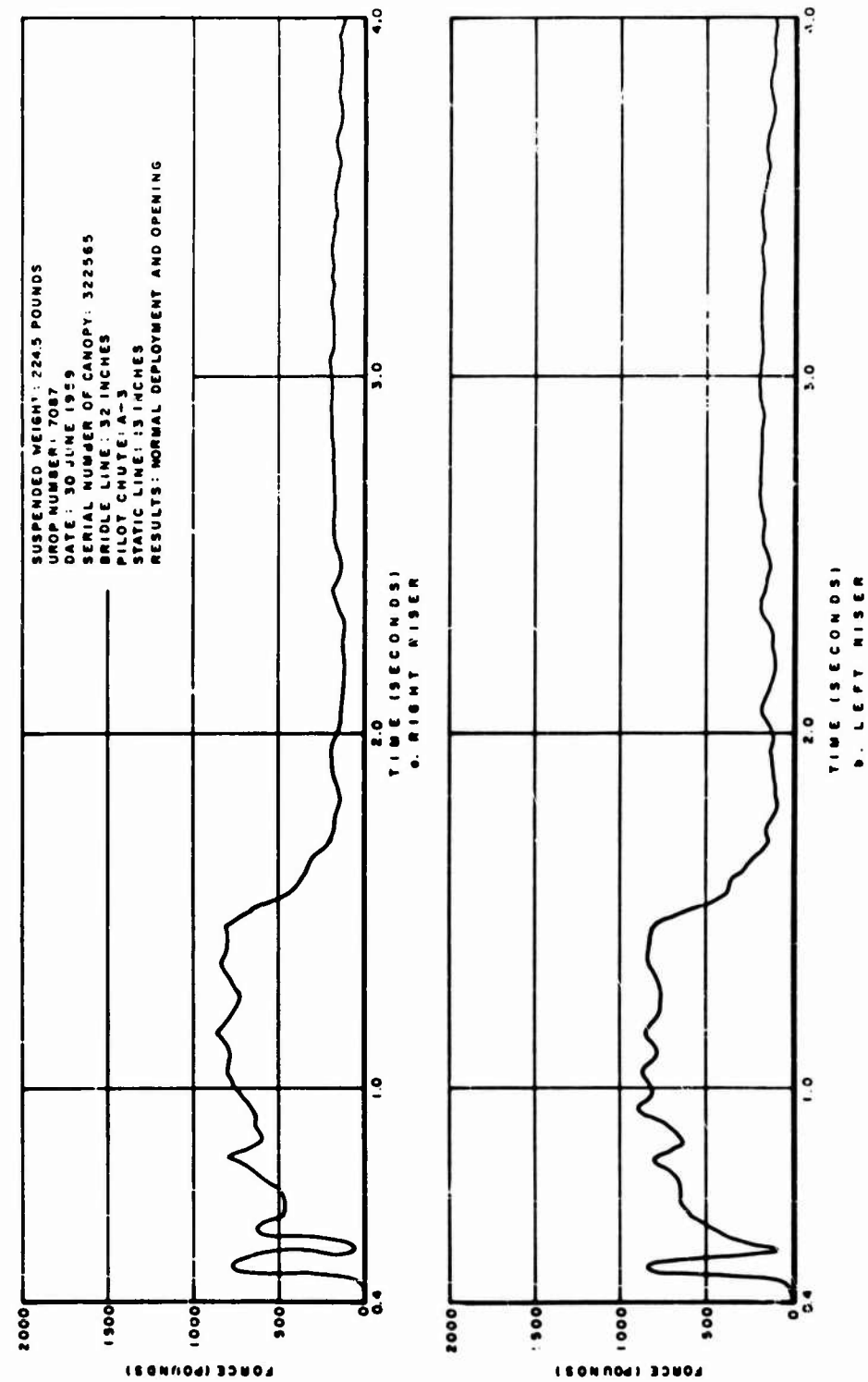


Figure 25. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 9 (Whirl-Tower Tests)

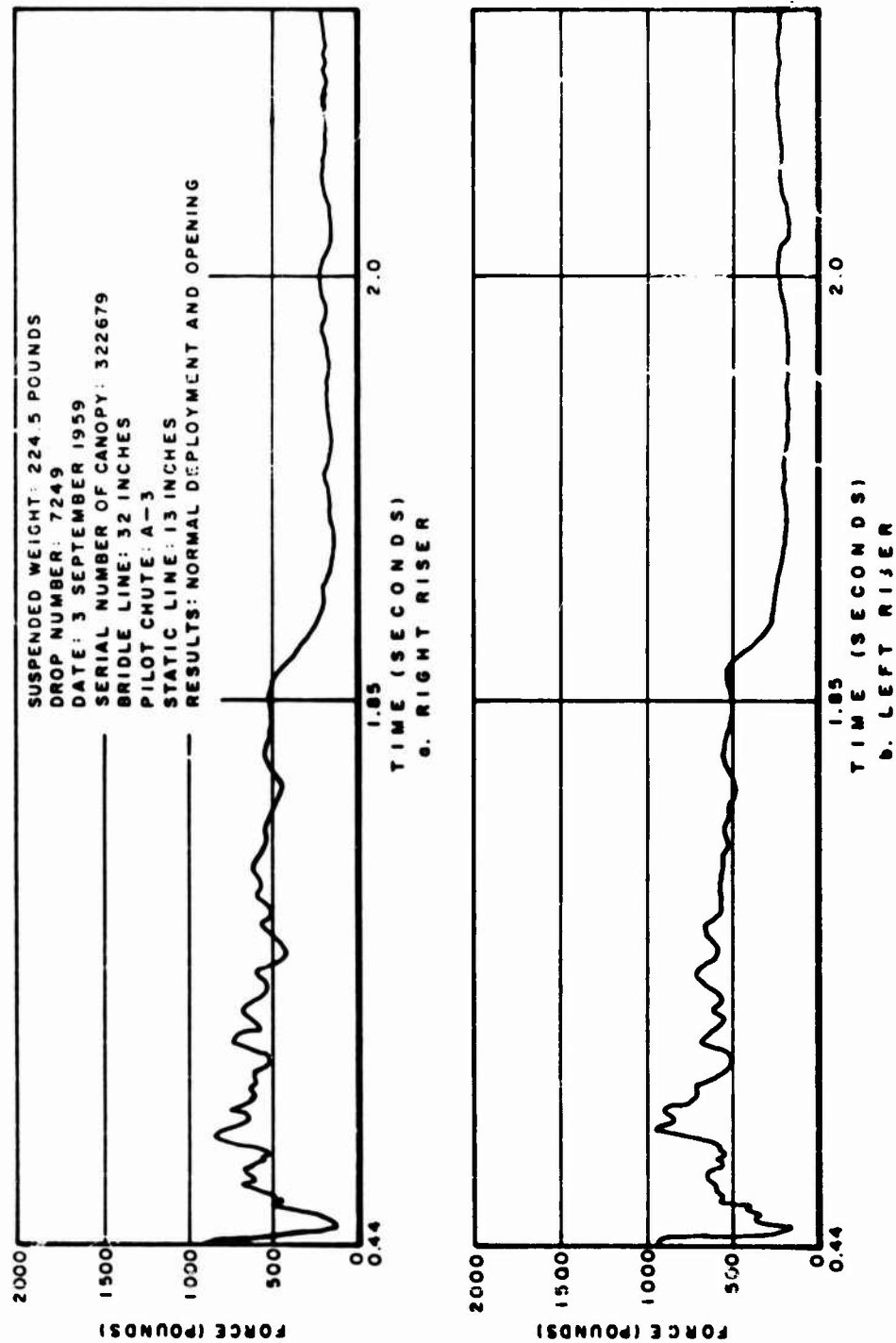


Figure 26. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 10 (Whirl-Tower Tests)

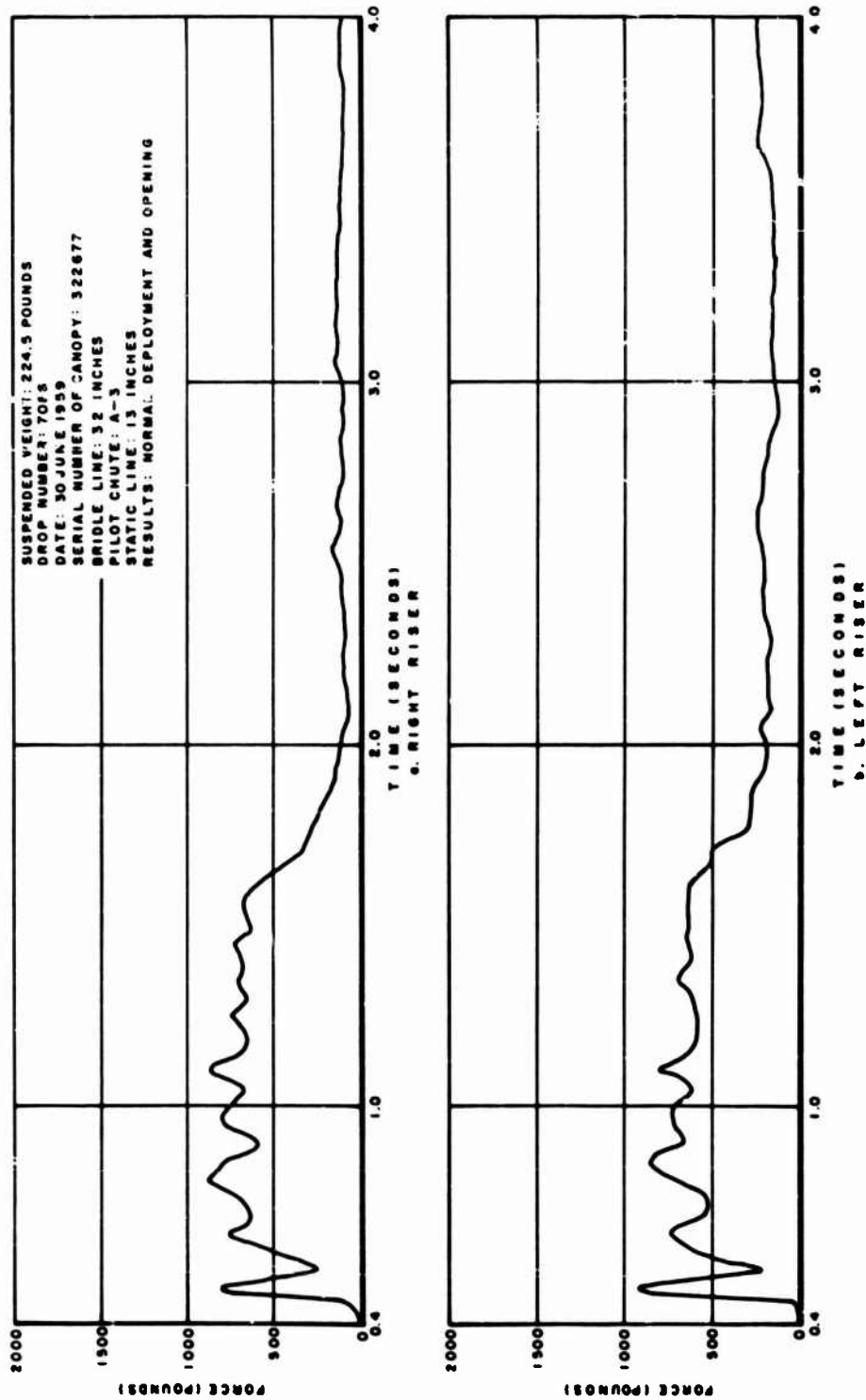


Figure 27. Force Versus Time of Canopy Opening at Release Velocity of 175 Knots for Group 11 (Whirl-Tower Tests)

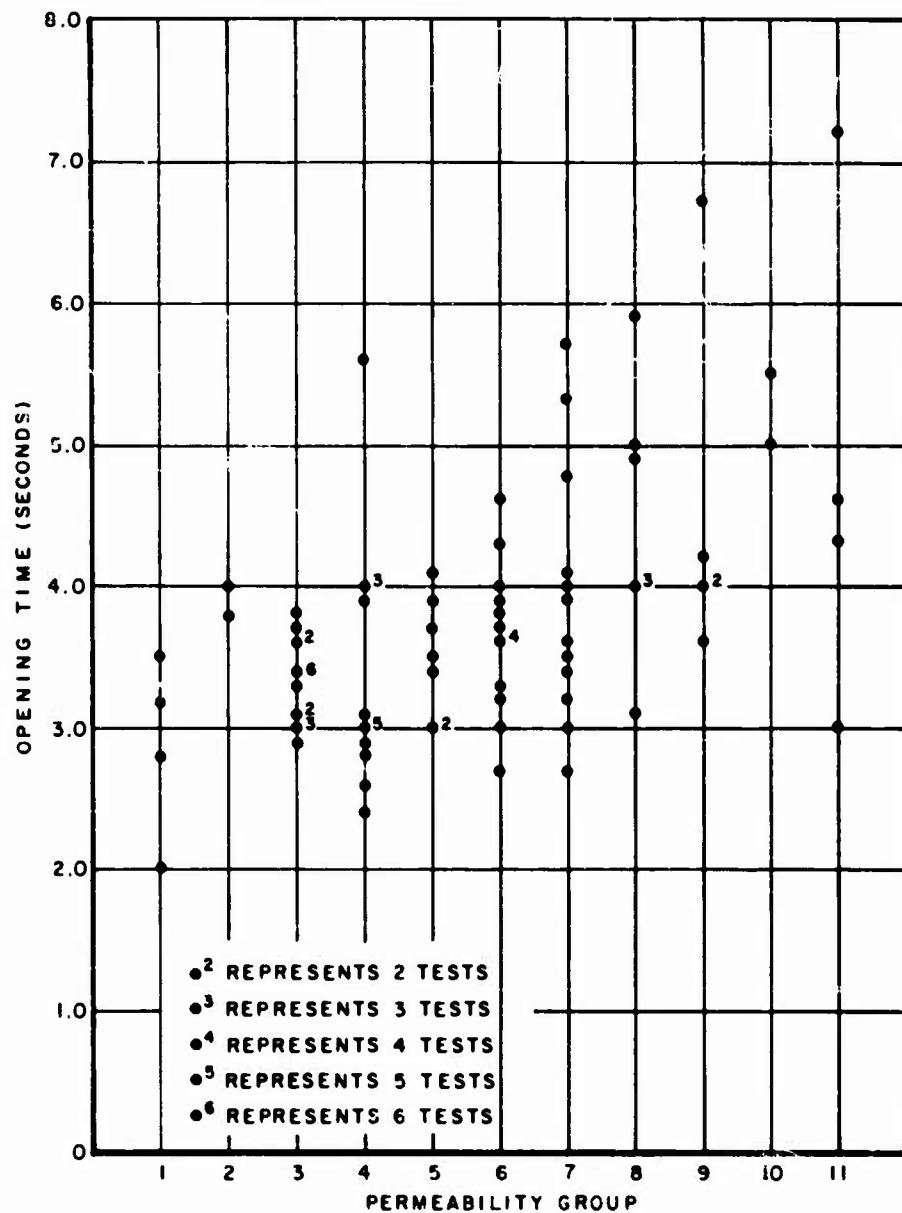


Figure 28. Opening Time of Canopy Versus Cloth Permeability Group for Twisted-Line Tests; Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)

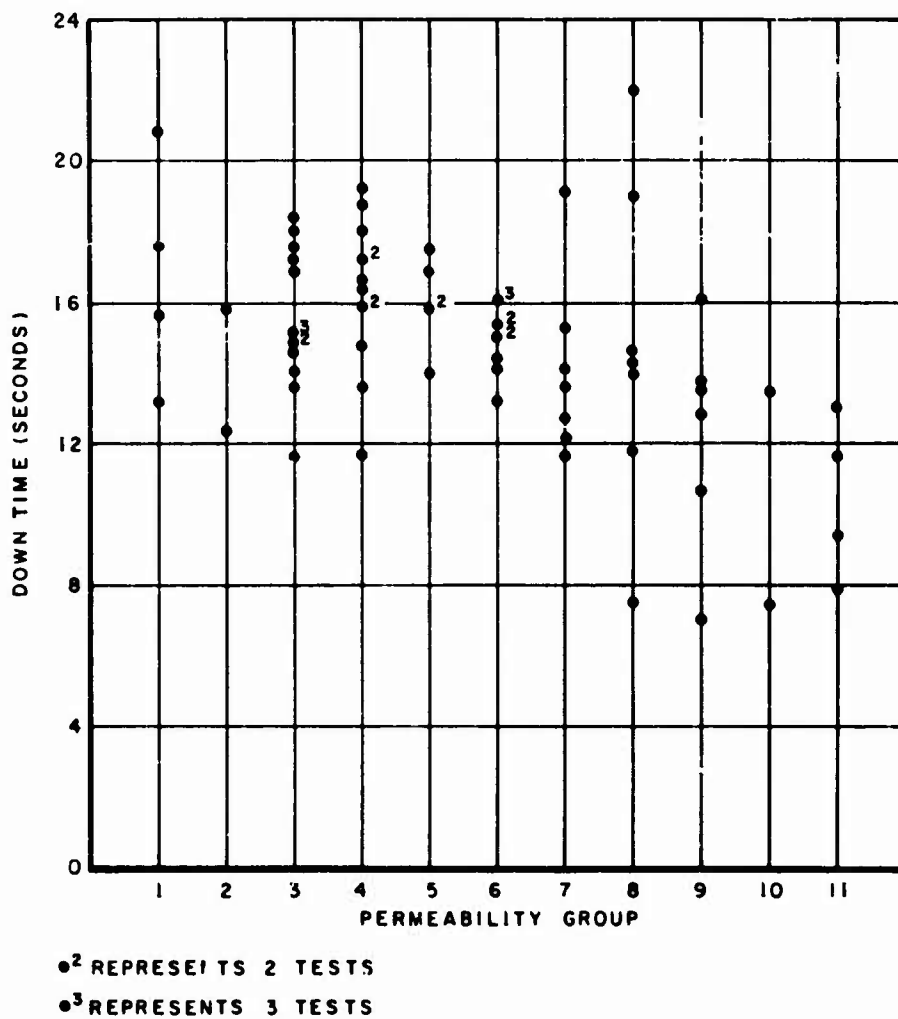


Figure 29. Down Time of Parachute Versus Cloth Permeability Group for Twisted-Line Tests; Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)

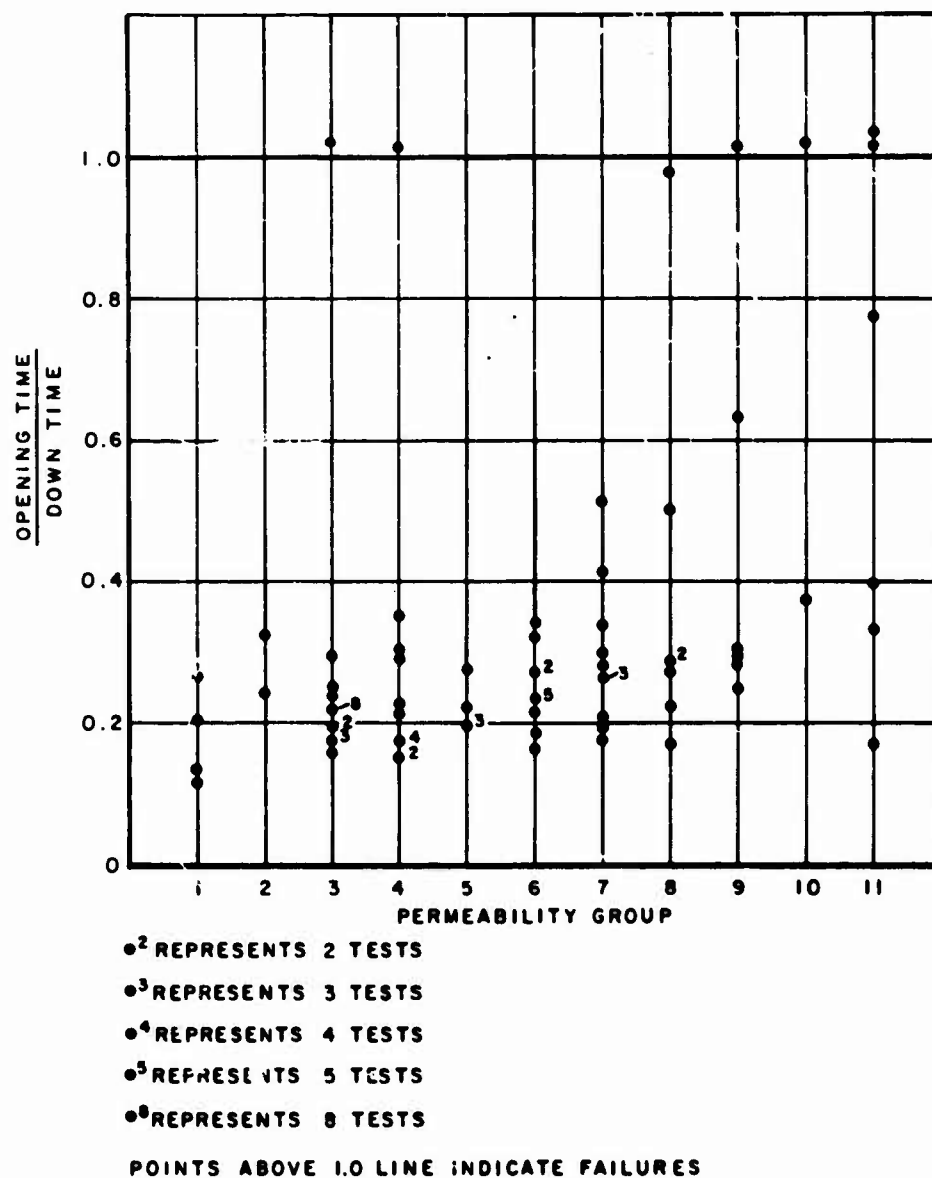
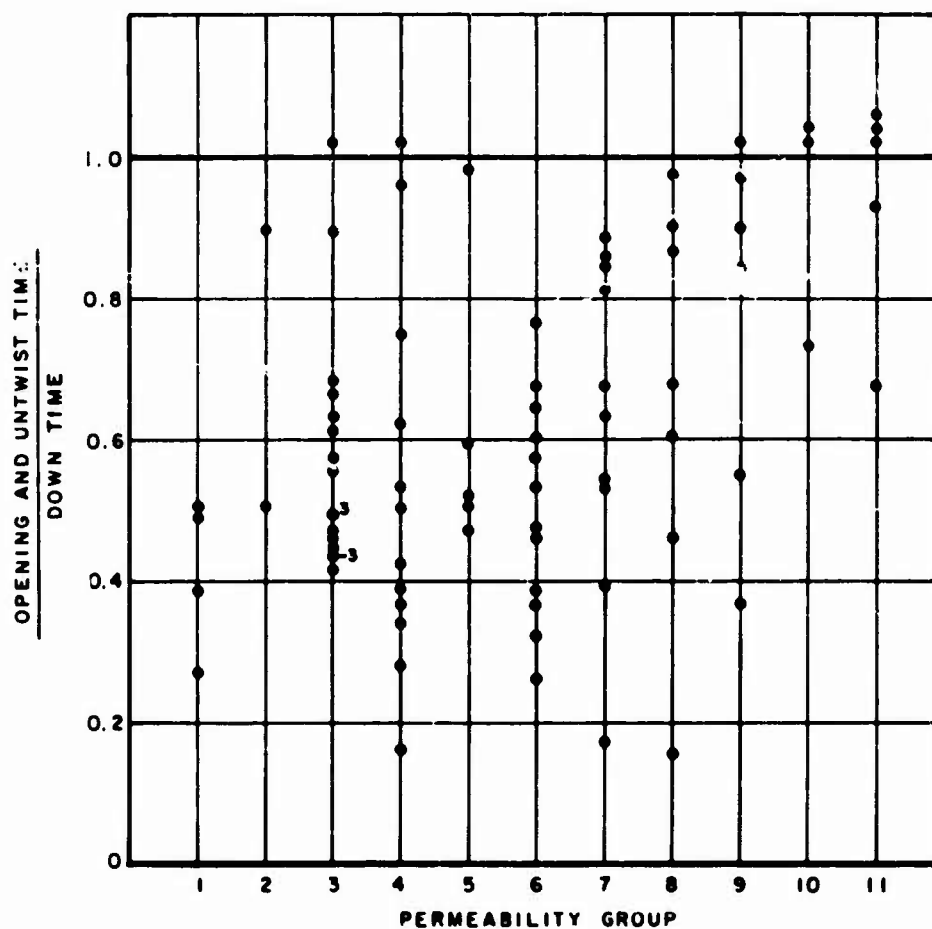


Figure 50. Ratio of Opening Time to Down Time Versus Cloth Permeability Group for Twisted-Line Tests; Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)



●³ REPRESENTS 3 TESTS

POINTS ABOVE 1.0 LINE INDICATE FAILURES

Figure 31. Ratio of Opening Time and Untwisted Time to Down Time Versus Cloth Permeability Group for Twisted-Line Tests; Release Velocity, 110 Knots; Altitude, 500 Feet (Drops from Aircraft)

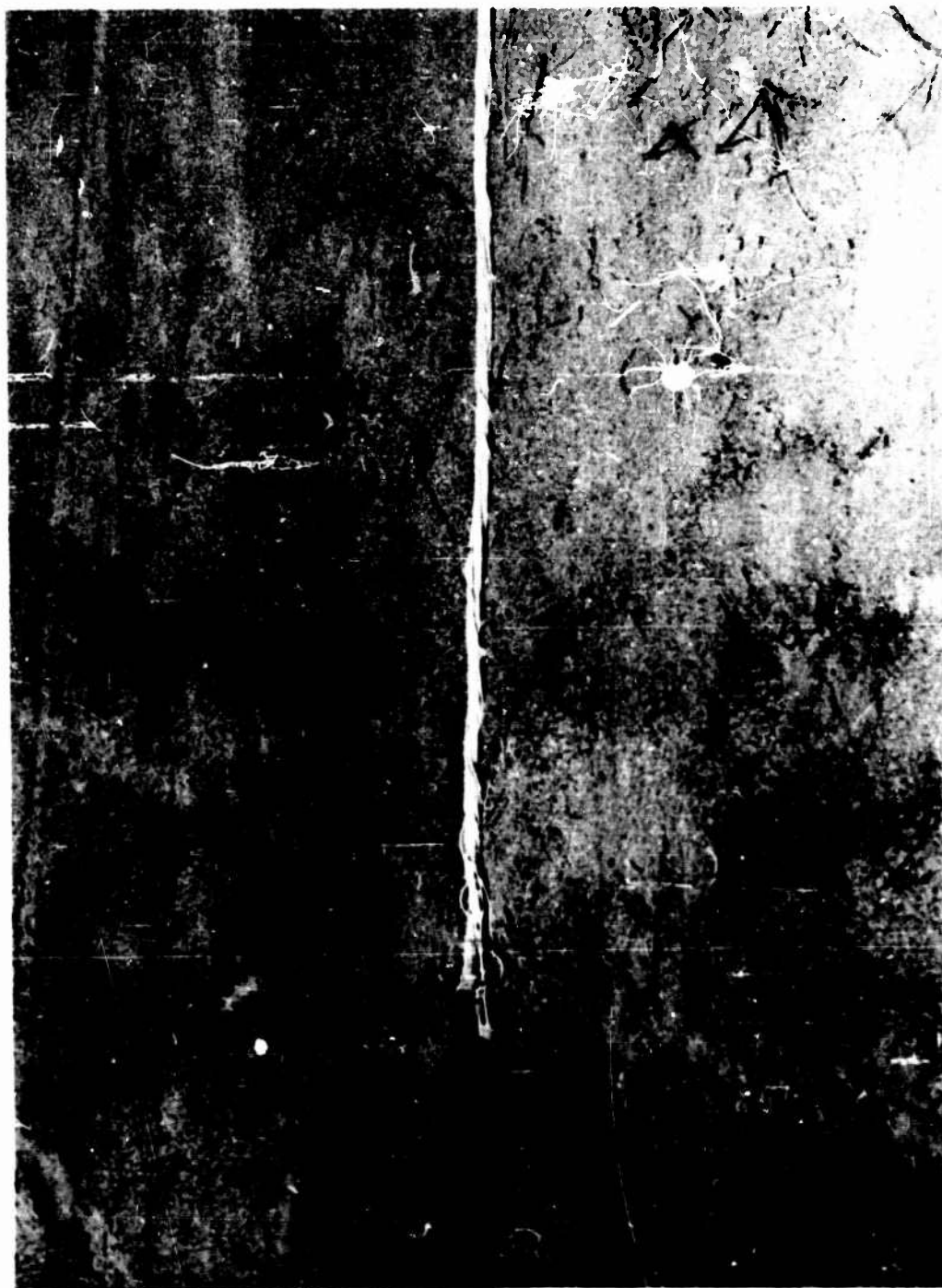


Figure 32. Twisted and Knotted Suspension Lines on a Parachute Canopy from Cloth Permeability Group 3 (Test No. 58-1053)

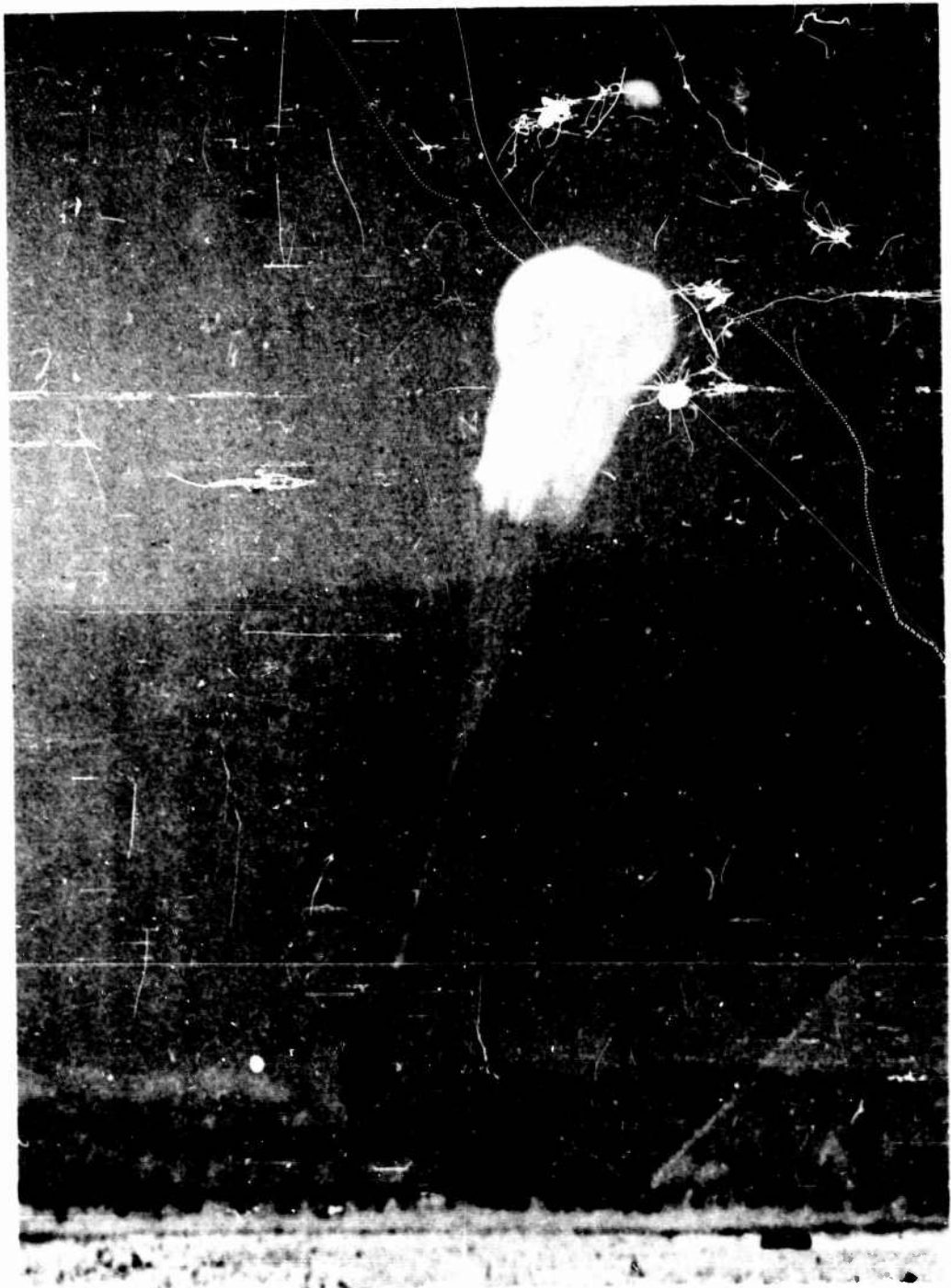
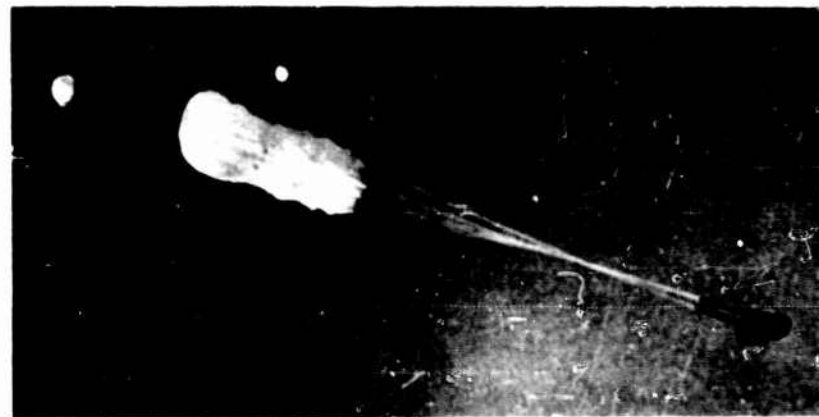


Figure 33. Canopy from Cloth Permeability Group 4 That Failed to Inflate Before Ground Impact. Suspension Lines are Knotted about Midpoint (Test No. 59-401)



a.

Note twisted suspension lines at beginning of inflation period.



b.

Canopy inflation has progressed very little; suspension lines still twisted.



c.

Suspension lines are now untwisted, but inflation has progressed very little. This photograph was taken shortly before ground impact.

Figure 34. Canopy from Cloth Permeability Group 9 That Failed to Inflate



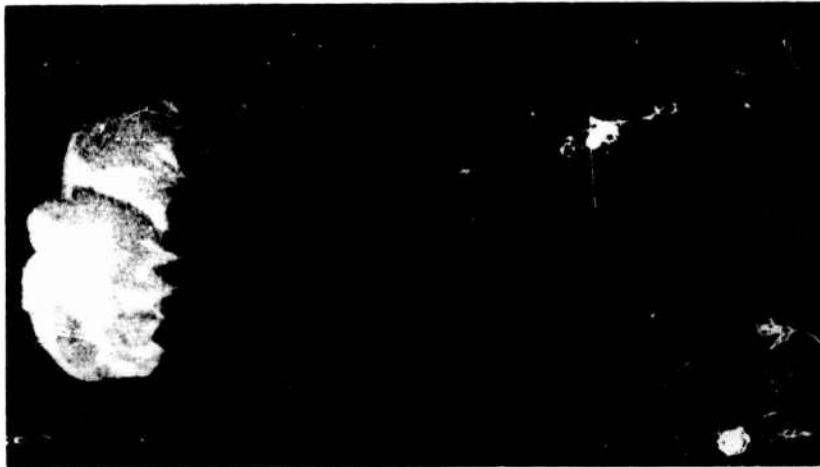
a.

Line twists shown at beginning of the inflation period.



b.

Canopy inflation is proceeding, but suspension lines are still twisted.



c.

Complete canopy inflation prevented because of suspension line over the canopy and suspension lines tangled at about the midpoint.

Figure 35. Canopy from Cloth Permeability Group 11 That Failed to Inflate

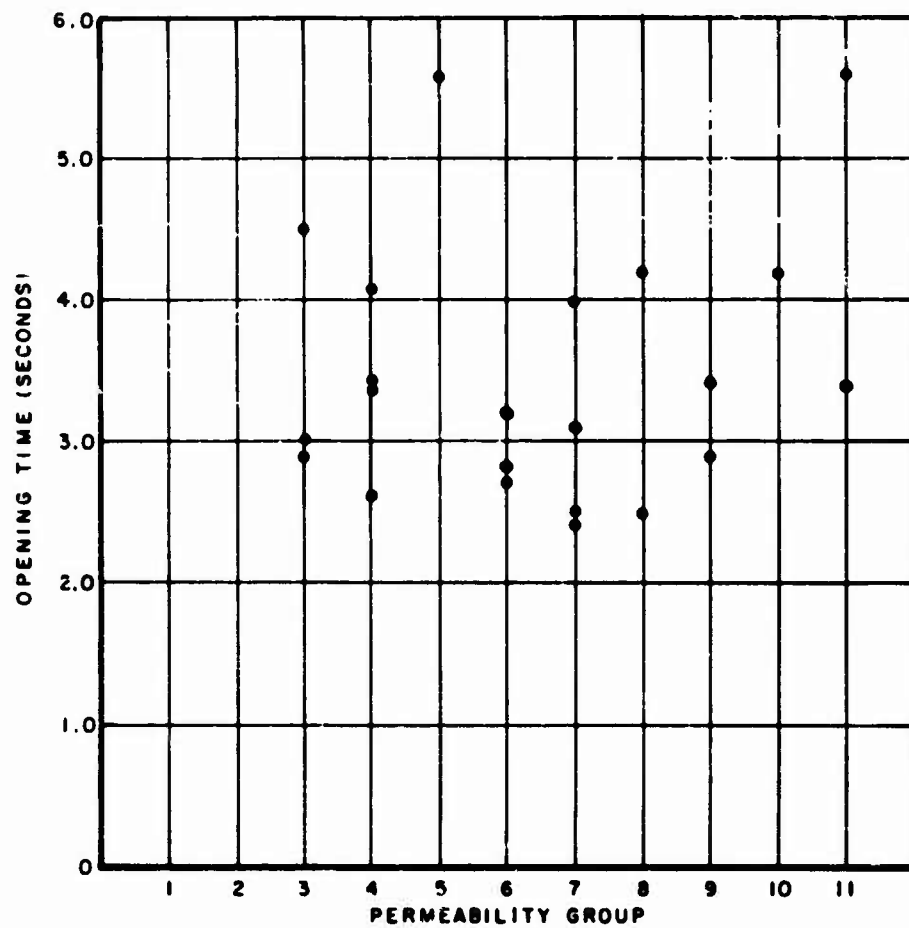


Figure 36. Opening Time of Canopy Versus Cloth Permeability Group for Twisted-Line Tests; Release Velocity, 150 Knots; Altitude, 500 Feet (Drops from Aircraft)

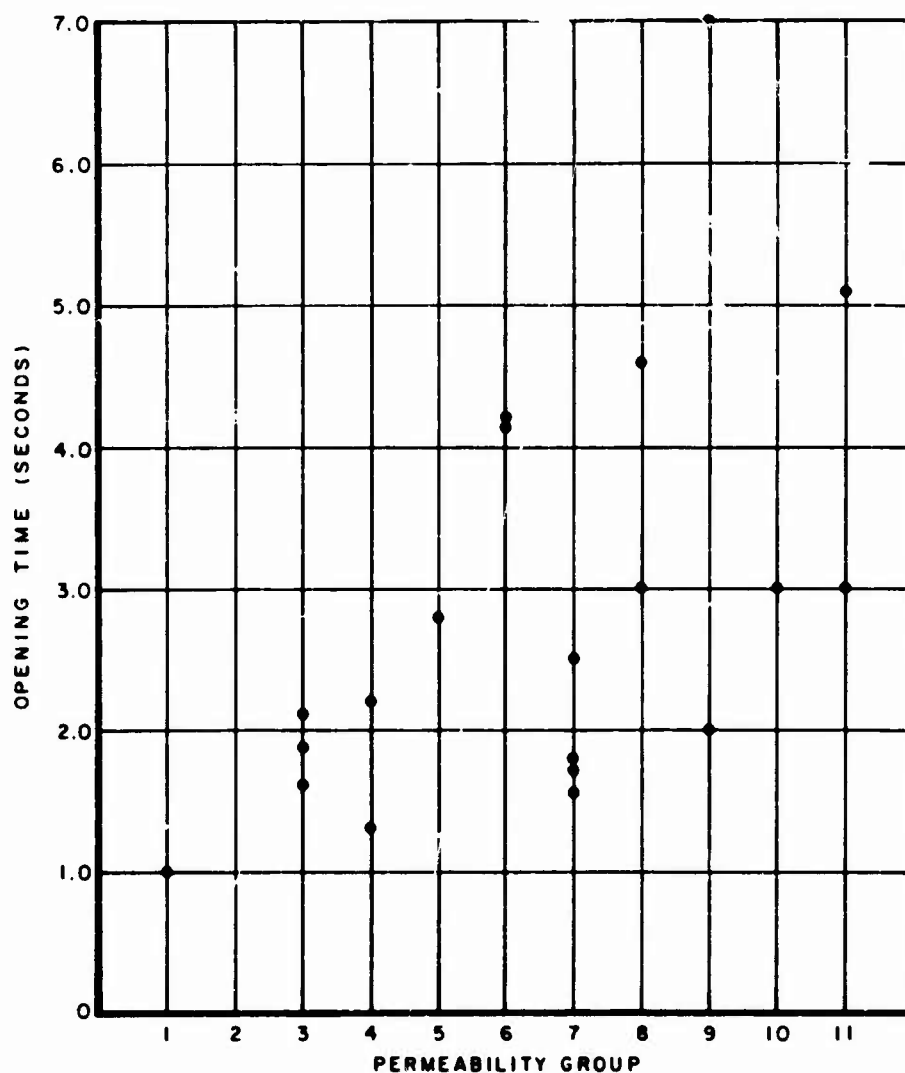
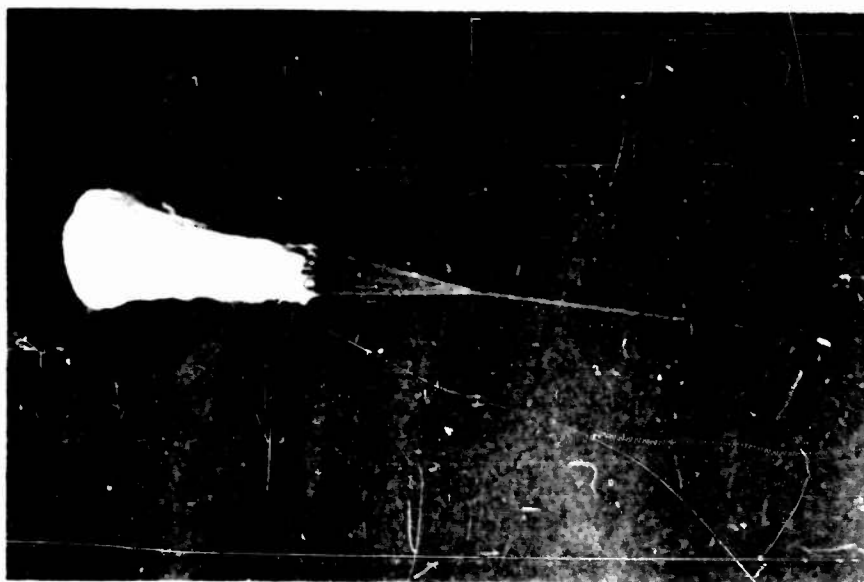
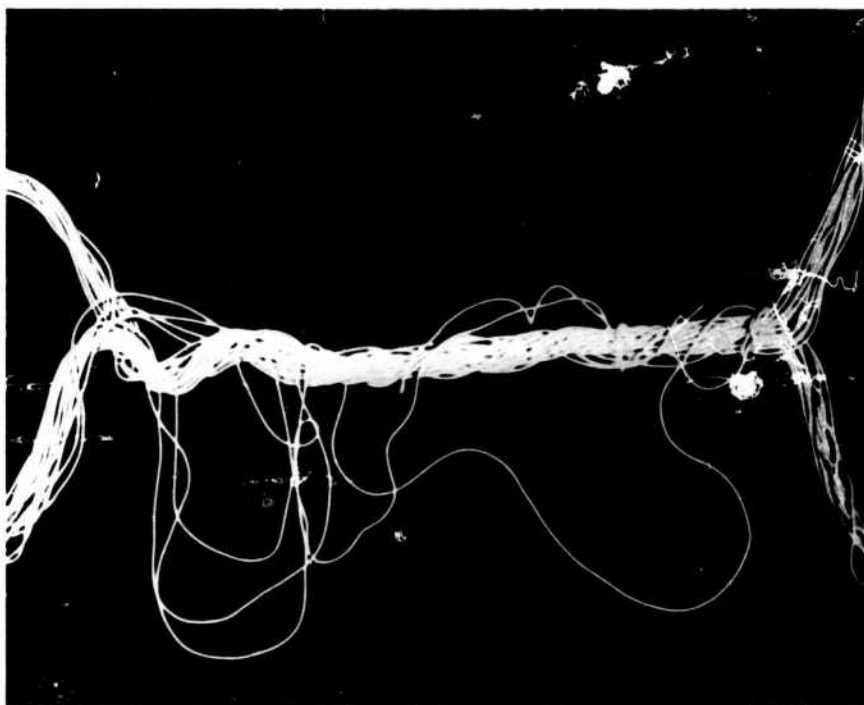


Figure 37. Opening Time of Canopy Versus Cloth Permeability Group for Twisted-Line Tests: Release Velocity, 225 Knots; Altitude, 500 Feet (Drops from Aircraft)



a.

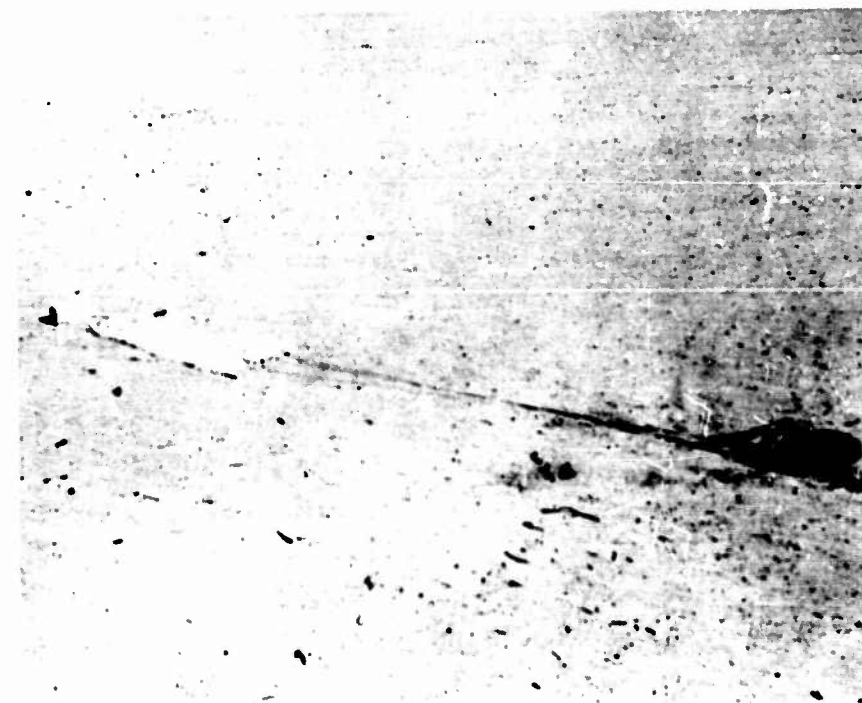
Suspension lines knotted above midpoint.



b.

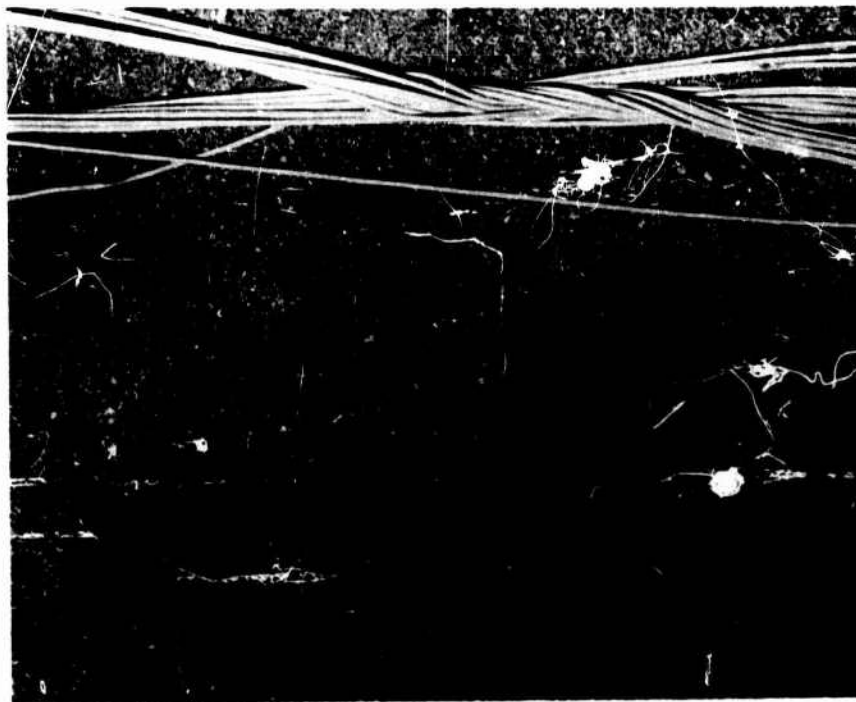
Closeup of twists and knots in suspension lines.

Figure 38. Canopy from Cloth Permeability Group 8 That Failed to Inflate: Release Velocity, 225 Knots



a.

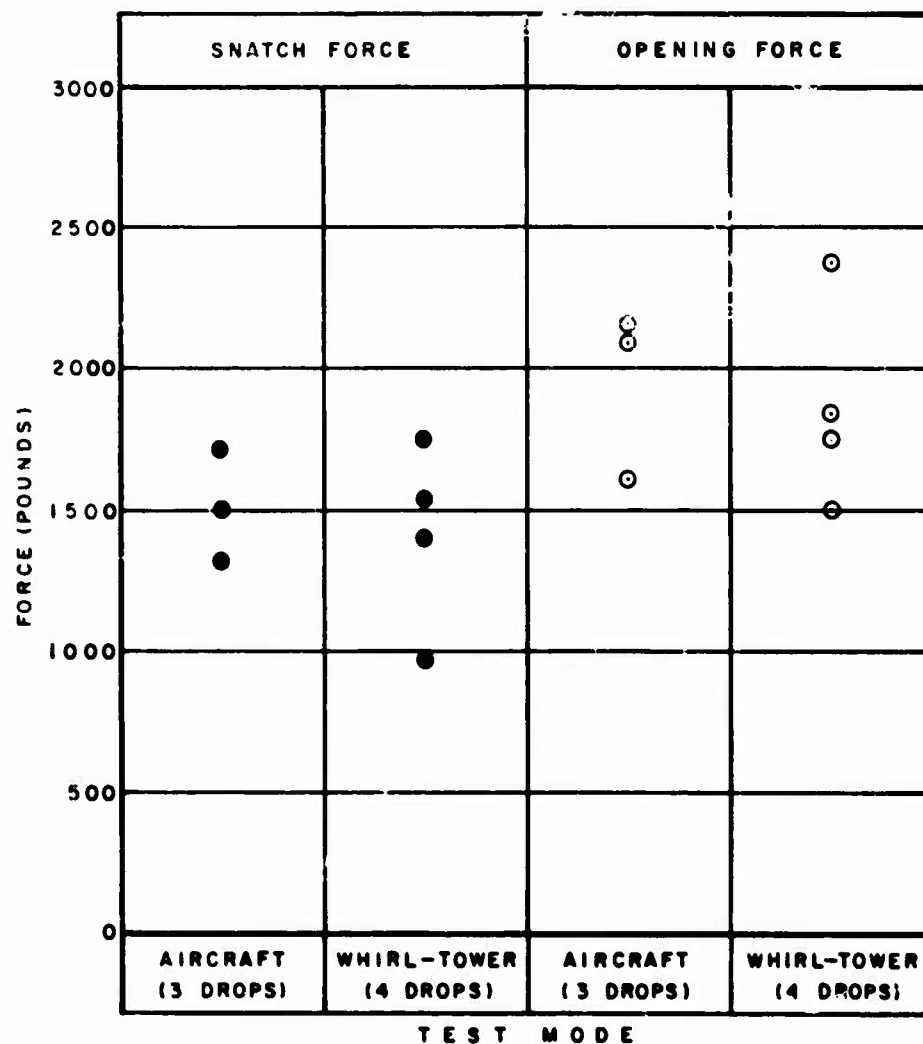
Note twists in suspension lines.



b.

Closeup of twists in the suspension lines.

Figure 5. Canopy from Cloth Permeability Group 11 That Failed to Inflate; Release Velocity, 225 Knots



ALL DROP TESTS MADE WITH PARACHUTE SERIAL NO. 322520
PERMEABILITY GROUP 6

Figure 40. Comparison of Canopy Snatch and Opening Forces Experienced During Drop Tests from Whirl Tower and Aircraft: Release Velocity, 150 Knots

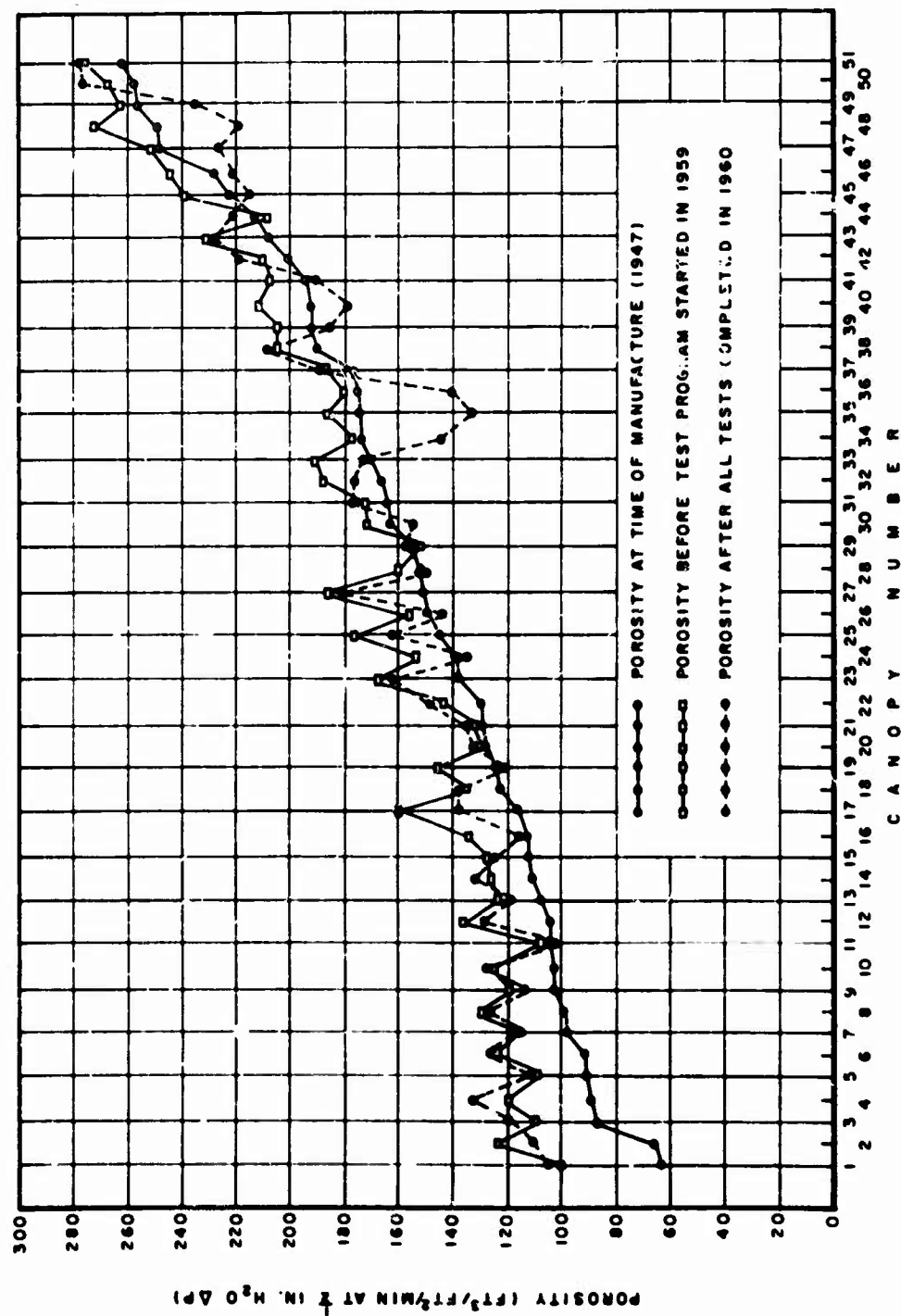


Figure 41. Average Cloth Permeability Values for All Available Canopies

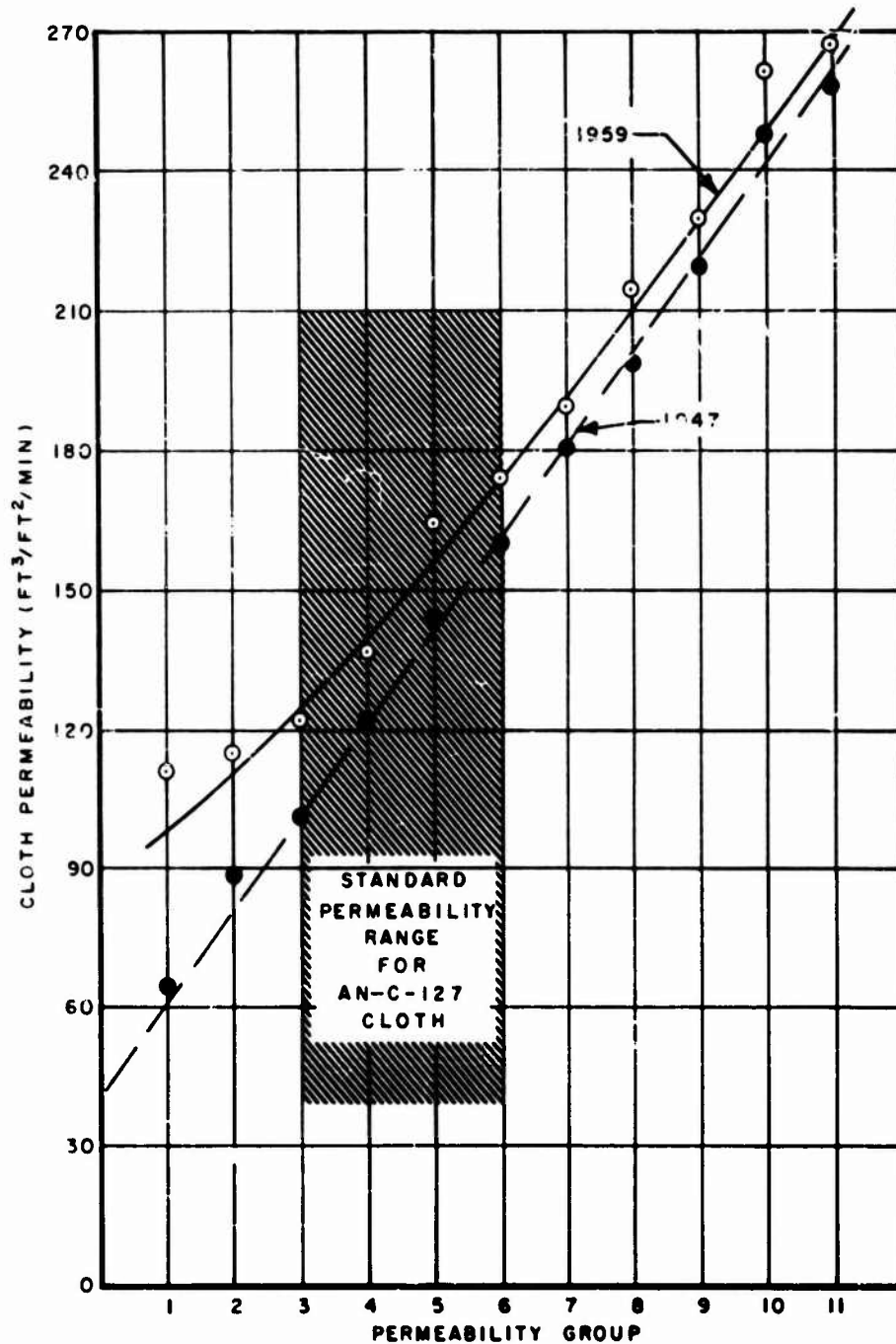


Figure 42. Average Cloth Permeability Values for All Permeability Groups in 1947 and in 1959 Before Initiation of Drop Testing

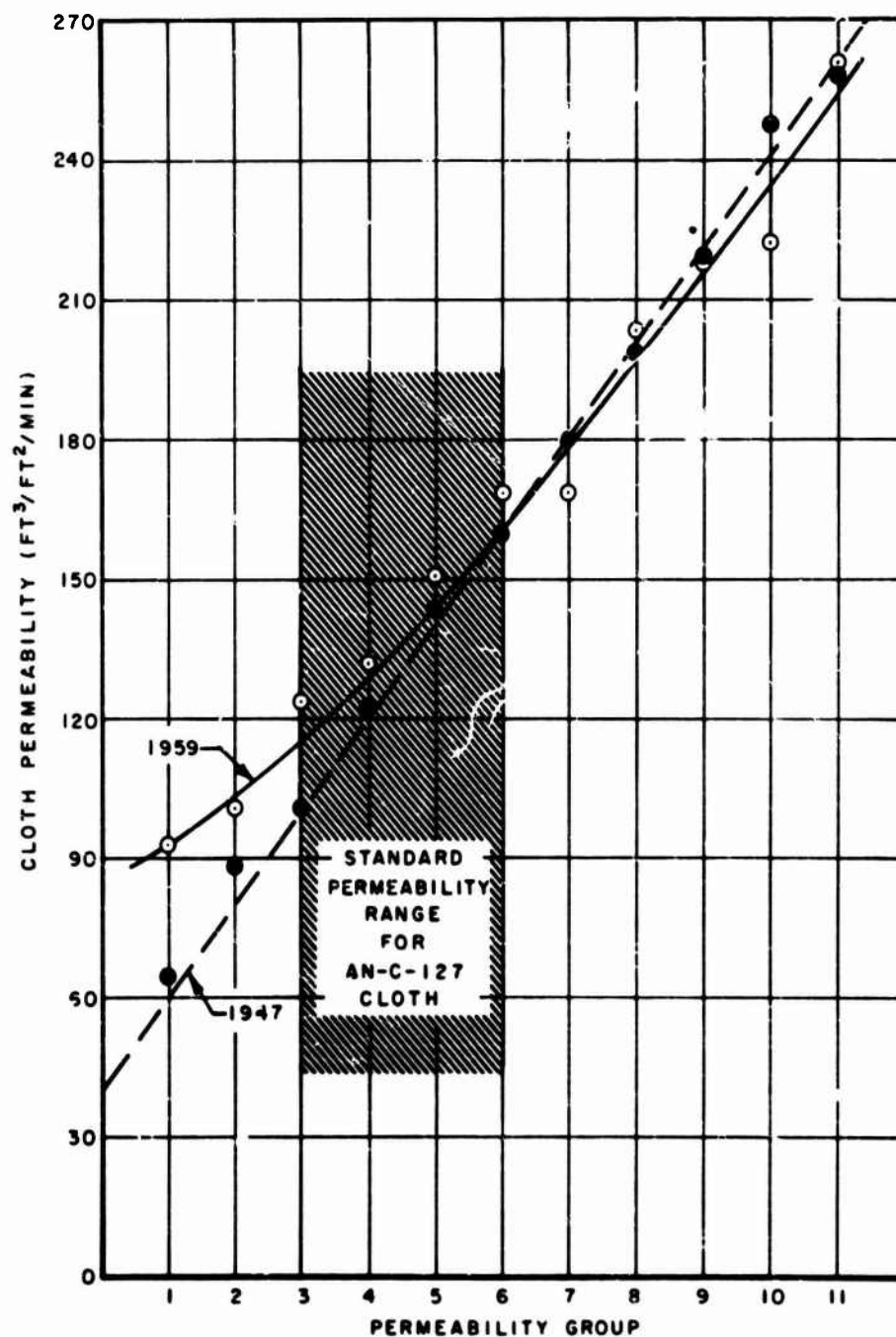


Figure 43. Average Cloth Permeability Values for All Permeability Groups in 1947 and in 1959 After Completion of Drop Testing

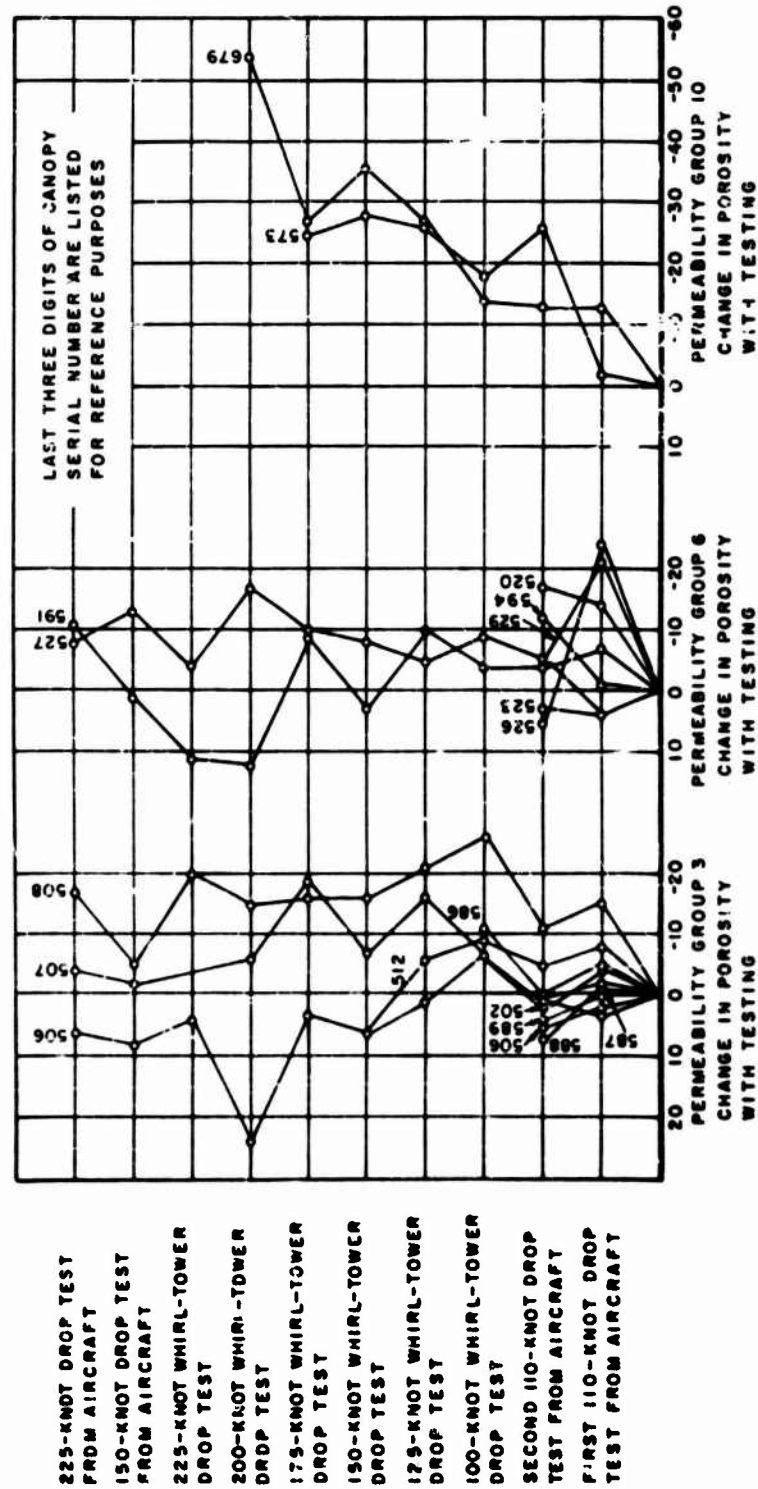


Figure 44. Change of Average Cloth Permeability with Number of Canopy Deployments for Three Permeability Groups

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 65p. Incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

(over)

1.6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

1. Parachute descents
2. Parachute fabrics
- I. AFSC Project 6065, Task 6065-03
- II. R. J. Gross
- C. V. Eckstrom
- III. In ASTIA collection

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 65p. Incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

(over)

1.6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 65p.
incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

1.6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

1. Parachute descents
2. Parachute fabrics
I. AFSC Project 6065,
Task 6065-03
II. R. J. Gross
C. V. Eckstrom
III. In ASTIA collection

Aeronautical Systems Division, Dir/Aeromechanics, Flight Accessories Lab, Wright-Patterson AFB, Ohio.
Rpt Nr ASD-TDR-62-413. PERFORMANCE EVALUATION OF PARACHUTE CANOPIES WITH VARIOUS CLOTH PERMEABILITIES. Jun 62, 65p.
incl illus., tables, 4 refs.

Unclassified Report

Parachute drops from aircraft and a whirl tower were conducted on parachute canopies that had been stored for 12 years to determine the effects of age upon cloth permeability and opening characteristics of the canopies. These flat-circular canopies were 24 feet in diameter and made of

1.6-ounce nylon cloth. They had permeabilities ranging between 50 to 270 cubic feet of air per square foot of cloth per minute. The canopies, originally fabricated in 1947, were subjected to "captive" whirl-tower testing at that time. After the 12-year storage, both cloth permeability and deployment of canopy tests were conducted to compare results with those obtained from 1947 tests of these same canopies. In addition, twisted suspension-line tests were conducted to validate all tests under actual operational conditions. The results of tests conducted confirm the relationship between cloth permeability and opening force and time. No essential changes in opening characteristics or cloth permeability were indicated after a 12-year aging period.

1. Parachute descents
2. Parachute fabrics
I. AFSC Project 6065,
Task 6065-03
II. R. J. Gross
C. V. Eckstrom
III. In ASTIA collection